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TESIS DOCTORAL:

ANÁLISIS DE FACTORES INFLUYENTES EN LA GESTIÓN DEL RECURSO MICOLÓGICO

Presentada por Pedro Ortega Martínez para optar al grado de Doctor por la Universidad de Valladolid

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DESDE EL CORAZÓN, GRACIAS A TODOS

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RESUMEN

En un contexto en el que las setas han incrementado considerablemente su valor, tanto económico como social, cobra sentido la expresión "gestión micológica", entendida ésta como el conjunto de actuaciones encaminadas a la protección, planificación y explotación del recurso micológico.

La presente tesis doctoral es un compendio de tres publicaciones que contribuyen a establecer una serie de criterios para conseguir con éxito la adecuada ordenación y regulación del recurso micológico.

Todas las publicaciones incluidas en la tesis han sido llevadas a cabo en el monte "Pinar Grande", una gran masa arbolada de *Pinus sylvestris* de 12.533 ha representativa de los pinares del Sistema Ibérico Norte peninsular, ubicada en la Comarca de Pinares de Urbión en Soria. La toma de datos y el diseño de metodologías se ha basado en la red de parcelas valladas y transectos permanentes establecida en 1995 por la Junta de Castilla y León en dicho monte.

En primer lugar se persigue diseñar un método de muestreo que recoja gran cantidad de información para, posteriormente, reinvertir la misma en el diseño de una metodología de muestreo más sencilla y orientada específicamente a la gestión micológica. Este método se basa en transectos permanentes en el que se reservan los carpóforos de un muestreo al siguiente, lo que permite desglosar la producción bruta en: producción recolectable, producción recolectada, producción consumida por fauna y producción malograda. Además, permite determinar el ancho de banda para cada especie micológica en sus respectivos hábitats, así como su peso medio, y el establecimiento de relaciones productivas.

En segundo lugar se ha estudiado la variación en el crecimiento (peso y diámetro) de los carpóforos en diferentes estadios de desarrollo de la planta hospedante. Se han observado, tanto para *Boletus edulis* como para *Lactarius deliciosus* marcadas diferencias en el crecimiento de los cuerpos fructíferos en masas jóvenes respecto de masas más maduras. El conocimiento de estas variaciones en el crecimiento facilitarán y perfeccionarán, además de la metodología de inventario, determinadas decisiones para la ordenación y regulación del recurso, como la planificación de actuaciones selvícolas o la determinación de zonas vedadas o tamaños mínimos de los carpórofos a recolectar.

Por último se abordan aspectos más sociales de la recolección de setas. El objetivo perseguido es la cuantificación, en términos económicos, del interés social generado por la recolección de setas aplicando el método del coste de viaje, mediante

el que se obtiene la curva de demanda del recurso y, a partir de ésta, el excedente del consumidor anual. Para el monte Pinar Grande, entre los años 1997 y 2005, se obtiene un valor medio de 21,41 € por coche (10,49 € por persona adulta) y varía entre 12,59 € por coche (6,05 € por persona) en 2005 y 28,73 € por coche (14,91 € por persona) en 2001. El conocimiento del excedente del consumidor y, a partir de este la disponibilidad a pagar por parte de los recolectores es necesaria de cara a implantar un sistema de permisos de recolección y fijar un precio unitario por tipo de permiso. Así, se obtiene que el coste de un permiso de recolección debería variar considerablemente con la bondad de la temporada de setas.

La gestión del recurso micológico con criterios prácticos y ajustada a la realidad sólo se puede conseguir con la ayuda de unos sólidos cimientos basados en criterios, asunciones y metodologías obtenidas a partir de la elaboración de estudios de investigación básica aplicada en micología, entre los que se enmarcan los tres recogidos en esta tesis.

ABSTRACT

In a context in which mushrooms have increased highly its social and economic value, the term “mycological management” has sense. Mycological management is a group of procedures aimed at protecting, planning and managing the mycological resources.

This doctoral dissertation is a compendium of three scientific papers that contributes to establish an issue of criteria to achieve successfully the suitable management and regulation of the mycological resources.

All the papers included here has been accomplished in “Pinar Grande” forest, a huge *Pinus sylvestris* stand of 12,533 ha that is representative of the Scots pine woods of the Sistema Ibérico Norte mountain range in the Pinares de Urbión region (Soria province, Spain). Collecting data and sampling methods design is based in the permanent fenced plot and transects net establised by the regional government of Castilla y León in 1995 in this stand.

First, a sampling method that collects a huge quantity of information in order to reinvest after it in the design of an easier sampling method especifically oriented to mycological magement is designed. This method is based in permanent transects in which sporocarps are kept from one sampling to the next, that allows to broke down the gross production in ripe production, harvested production, production eaten by fauna and damaged production. It also make possible to determine the band wide for each sporocarp fungal species in its habitat, as well as its mean weight and the set of its productive relationships.

Second, the tree age influence on the development, weight and cap diameter, of the sporocarps is analized. There are marked differences in the growth of *Boletus edulis* and *Lactarius deliciosus* sporocarps in young stands comparing old stands. Knowledge of those growth variations, also with the sampling method, will provide and improve the making of decisions for the management and the regulation of mycological resource, as well as the sylvicultural management or the determination of reserve areas or minimum sizes for sporocarps harvesting.

Finally, social implications of mushrooms picking are analized in order to quantify the social intereset that it arose, in an ecomomic order, using the travel cost model. This model calculates first the demand curve for the edible mushrooms and follow it, after, estimates the consumer surplus. In Pinar Grande stand, between 1997 and 2005, a mean value of 21.41 € per car (10.49 € per adult), ranging between 12.59 € per car (6.05 per adult) in 2005 and 28.73 € per car (14.91 € per adult) in 2001 is

obtained. In order to instil a system of user-pays fees and to fix unitary prices for each harvesting licence, the consumer surplus and consequently the disponibility by the harvesters must be know. Harvest fees should be changed according to the mushrooom production of the season.

Mycological resource management using useful criteria and fitting them to the reality, could be achieved only with the help of a firm groundwork, based in criteria, assumptions and methods obtained from the basic research in mycology, in which framework are the three papers compiled here.

INTRODUCCIÓN GENERAL

1 INTRODUCCIÓN

1.1 Ordenación del recurso micológico

Es una tradición acuñada en las sociedades rurales (especialmente en zonas forestales) la intervención de los montes según el interés predominante. Es conocido por todos la implicación que los habitantes de estas áreas mostraban hacia el cuidado del monte ya que, el aprovechamiento forestal (maderero, pastos, resina, caza, etc.) que obtenían del mismo suponía su principal fuente de ingresos. Esta utilidad del monte involucraba a sus beneficiarios en el mantenimiento y cuidado del mismo, razón por la cual, dichas zonas han sido gestionadas para el aprovechamiento de un determinado producto forestal.

En la actualidad la gestión forestal se materializa en planes de ordenación que recogen todos los criterios y directrices a seguir en un determinado ámbito. Desde hace tiempo los gestores de montes han incluido en sus planes de ordenación otros recursos forestales no maderables sin perder de vista en ningún momento el producto final por excelencia, la madera. En la actualidad, las nuevas orientaciones de consumo y por tanto de producción, las importaciones de materias primas o las nuevas "funciones sociales" del monte hacen que recursos como el micológico cobren fuerza y deban empezar a ser tenidos en cuenta en las ordenaciones forestales. Gracias a estas reorientaciones, muchas de las masas forestales que han perdido la rentabilidad y estabilidad que antaño tenían, serán revalorizadas, pasando a contar con un rol social y económico relevante.

Tradicionalmente, la ordenación de montes perseguía tres objetivos:

1. Persistencia y estabilidad.
2. Maximización de utilidades.
3. Rendimiento sostenido.

Todos estos objetivos deben ser considerados en la ordenación del recurso micológico. Un plan de ordenación determinará las directrices y actuaciones a realizar a largo plazo para cumplir con esos objetivos. La planificación a corto plazo del aprovechamiento se realizará a través de la regulación, abordada posteriormente.

Recientemente ha cobrado fuerza el término "selvicultura fúngica" (Oria de Rueda Salgueiro, 2007; Oria de Rueda Salgueiro *et al.*, 2008; Savoie & Largeteau, 2011) o micoselvicultura (Martínez-Peña & Rondet, 2008; Martínez-Peña *et al.*, 2011c) para definir aquellas prácticas selvícolas favorecedoras de la producción y diversidad de carpóforos, o dicho con otras palabras, aquellas prácticas que enmarcadas en un plan de ordenación pretenden alcanzar los tres objetivos citados, en especial el de persistencia y estabilidad.

En concreto, la ordenación del recurso micológico es importante para conseguir los siguientes objetivos:

- Arbitrar un sistema de inventario y control de la producción y el aprovechamiento que garantice la sostenibilidad del recurso micológico.
- Realizar una selvicultura y aprovechamientos forestales compatibles con la conservación de la producción y diversidad del recurso.
- Compatibilizar el aprovechamiento micológico con el resto de aprovechamientos y usos forestales.
- Maximizar la utilidad socioeconómica generada directa o indirectamente por el aprovechamiento micológico en las comarcas forestales, contemplando:
    - Las posibles rentas generadas para la propiedad forestal por la adjudicación de este aprovechamiento, según las diferentes modalidades de regulación de la recolección.
    - Las rentas directas a los recolectores por autoconsumo o comercialización.
    - El valor añadido por empresas de compraventa y transformación.
    - El valor añadido por micoturismo (gastronomía, pernoctación, servicios micológicos, etc.).
    - El valor recreativo y satisfacción social generada por la recolección de setas.
- Potenciar las repoblaciones y gestión de plantaciones en terrenos agrícolas marginales con planta micorrizada con hongos de interés comercial.
- Garantizar la calidad y seguridad de la comercialización de los hongos silvestres comestibles.

Cabe reseñar, llegados a este punto, los Planes de Ordenación de los Recursos Forestales (PORF), cuyo ámbito de actuación es óptimo para ordenar y regular el recurso micológico. En ellos se contempla un diagnóstico a escala comarcal del recurso micológico y demás recursos forestales, se definen unas directrices de gestión y la posibilidad de concretar mediante normativa las modalidades de aprovechamiento más adecuadas y sus condiciones técnicas para cada comarca.

La ordenación del recurso micológico debe seguir avanzando hacia modelos que permitan su conservación, maximización y compatibilización con otros recursos forestales. En este punto, los trabajos de investigación en micología forestal aplicada juegan un papel relevante ya que sentarán las bases y criterios generales de ordenación del recurso.

1.2 Regulación de la recolección

El creciente interés por el recurso micológico ha generado una serie de beneficios económicos (micoturismo, gastronomía micológica o compraventa de setas) y sociales (ocio y esparcimiento o desarrollo rural) que han puesto de manifiesto la valiosa aportación del recurso en el desarrollo de las poblaciones rurales y la necesidad de una regulación encaminada hacia una gestión sostenible del mismo.

El *"desarrollo sostenible"* impulsa, en esencia, el aprovechamiento de los recursos naturales sin agotarlos, manteniéndolo en el tiempo y en el espacio, evitando, en lo posible, impactos ambientales negativos. En el momento en el que un recurso es explotado masivamente y corre peligro de desaparecer o ser dañado de manera considerable, es cuando se debe plantear la ordenación del mismo.

La regulación de la recolección de hongos silvestres constituye una herramienta necesaria para la consecución de los objetivos planteados en un plan de ordenación. La base temporal de la regulación es reducida. Debe ser diseñada para el corto/medio plazo ya que en caso contrario perdería la misión operativa que ostenta. Los criterios de regulación deben ser modificados o recalculados periódicamente en cortos espacios de tiempo.

Como respuesta a esta necesidad de regulación, la vigente ley de Montes (Ley 43/2003 de 21 de noviembre) incluye en su articulado una referencia expresa a la regulación de los aprovechamientos forestales (art. 36), en la cual se atribuye al titular del monte la propiedad de los recursos forestales (entre otros, las setas) producidos en el mismo. Con esto queda claro que, como quizás podía entenderse hasta el momento, las setas no son "res nullius" y que, por lo tanto, pertenecen a los titulares de los terrenos donde se encuentren (García Asensio, 2004).

El reciente Real Decreto 30/2009, de 16 de enero, por el que se establecen las condiciones sanitarias para la comercialización de setas de uso alimentario, establece una nueva línea normativa cuyo objetivo es el de aportar mayor seguridad sanitaria e higiénica, así como el control de las transacciones realizadas con setas.

Por su parte, la Junta de Castilla y León abordó la necesidad de regulación del recurso micológico mediante el Decreto 130/1999, de 17 de junio, por el que se ordenan y regulan los aprovechamientos micológicos en los montes ubicados en la Comunidad de Castilla y León. Este primer instrumento legislativo para la regulación micológica recogió medidas de carácter general, además de un régimen sancionador, aunque con la limitación de que la regulación del aprovechamiento únicamente es de aplicación a montes de Utilidad Pública y de propiedad de la Junta de Castilla y León.

El modelo de regulación Myas (Micología y Aprovechamiento Sostenible) comenzó, en torno al año 2000, como una experiencia piloto de regulación de la recolección de setas en la comarca de Almazán (Soria). Se trata de un proceso participado y a demanda basado en un sistema de permisos de recolección que discrimina positivamente a la población residente en los municipios propietarios de los montes productores, garantiza la recolección recreativa a la población foránea y camina hacia la mejora, profesionalización y sostenibilidad del aprovechamiento. En la actualidad, y dada la funcionalidad del proyecto, este modelo se está implantando en el resto de la Comunidad Autónoma afectando a más de 335000 ha (www.myasrc.es).

Señalización de una zona con aprovechamiento micológico regulado.

Con todo lo anterior, parece claro que, con el apoyo, principalmente económico y normativo, de las Administraciones Públicas y la concienciación del resto de los agentes implicados en el aprovechamiento del recurso micológico, se está avanzando de forma positiva, consensuada y ordenada hacía una regulación eficaz del recurso, única herramienta garante de la conservación y el aprovechamiento sostenible del recurso micológico.

1.3 Importancia socioeconómica de los hongos silvestres comestibles. Principales especies

Los carpóforos de los hongos silvestres comestibles han sido utilizados históricamente con fines alimenticios y medicinales por muchas y diferentes culturas en todo el mundo. Hoy en día, más de 80 países aprovechan estas especies en sus territorios, estimándose un total de 2.327 especies utilizadas por el ser humano, de las que sólo una pequeña parte se comercializan (Boa, 2004).


Boletus edulis Bull. en pinares de *Pinus sylvestris* L..

Entre las especies más valoradas se encuentran *Boletus edulis* Bull. y *Lactarius deliciosus* (L.) Gray. El grupo *B. edulis* (*B. edulis*, *B. aereus* Secr., *B. pinophilus* Pilát & Dermek, y *B. reticulatus* Boud.) cuenta con una elevada importancia dada su comestibilidad (Hall *et al.*, 1998; Singer, 1986), siendo uno de los grupos de hongos más consumidos a lo largo del mundo. Estas especies son recolectadas únicamente en estado silvestre (Cannon & Kirk, 2007), no habiéndose obtenido por producción controlada hasta el momento. El consumo mundial del grupo *B. edulis* se cifra entre 20.000 y 100.000 toneladas al año y los mercados más importantes se encuentran en Norte América, Francia, Italia y Alemania (Hall *et al.*, 1998).


Lactarius deliciosus (L.) Gray.

Lactarius deliciosus no es una especie tan valiosa desde el punto de vista culinario pero también cuenta con un mercado muy consolidado que mueve grandes cantidades de setas. En nuestro país la región que más aprecia esta especie es Cataluña (Voces *et al.*, 2012). Además, los níscalos son comercializados de manera considerable en otros países de Europa, Asia y África del Norte, generando una importante fuente de ingresos (Boa, 2004).

El cambio de tendencia sufrido en los últimos años hace que la recolección de hongos sea considerada en la actualidad como uno de los motores de desarrollo en las zonas más desfavorecidas, ofreciendo una oportunidad a su población para aumentar su nivel de vida al ver aumentados sus ingresos (Wang & Hall, 2004) y jugando en contra de la tendencia despobladora del medio rural de las últimas décadas al promover actividades generadoras de riqueza económica y social de marcado carácter urbano.

En la Comunidad de Castilla y León, el aprovechamiento del recurso micológico ha alcanzado un elevado grado de desarrollo. Su territorio forestal presenta una gran aptitud para la producción y el aprovechamiento de hongos silvestres comestibles, entre los que se encuentran las especies más cotizadas en el mercado mundial como: *Boletus* grupo *edulis, Lactarius* grupo *deliciosus, Morchella* spp.*, Cantharellus cibarius* Fr.*, Tuber melanosporum* Vitt.*, Amanita caesarea* (Scop.) Pers.*, Calocybe gambosa* (Fr.) Donk, *Marasmius oreades* (Bolton) Fr.*, Pleurotus eryngii* (DC.) Quél.*, Tricholoma portentosum* (Fr.) Quél.*, T. aestivum* Vitt.*, Hygrophorus* spp.*, Hygrophorus marzuolus* (Fr.) Bres.*, Helvella* spp.*, Lepista* spp.*, Macrolepiota* spp.*, Agaricus* spp. La producción media generada por dichos hongos silvestres comestibles, en los montes de Castilla y León, se ha valorado en 80 millones de euros/año, pudiéndo llegar a triplicarse este valor en años buenos (Martínez-Peña *et al.*, 2007).

Particularizando a dos de las especies más relevantes, destacar que la producción de *B. edulis* en Castilla y León es de casi 1.600 toneladas, cuyo valor asciende a 1,5 millones de euros. Por otro lado, la producción de *L. deliciosus* es de 5.500 toneladas, cuyo valor aproximado es de 16,6 millones de euros (Martínez-Peña *et al.*, 2007). Actualmente, la recolección de setas implica al 54% de la población rural de Castilla y León, lo que supone 567.715 recolectores potenciales. El 14% de dicha población vende el producto recolectado, estimándose una capacidad para recolectar y comercializar de hasta 17.543 toneladas de setas en años de buena producción, con una generación potencial de rentas directas a los recolectores de 65 millones de euros al año (Martínez-Peña *et al.*, 2007).

En la Figura 1 se detallan las principales especies recolectadas para el autoconsumo y la compraventa en Castilla y León. Cabe destacar que el 34,5% de la población rural recolecta níscalos (grupo *L. deliciosus*) el 24,5% seta de cardo (*P. eryngii*) y el 19,3% *B. edulis* (Martínez-Peña *et al.*, 2007).

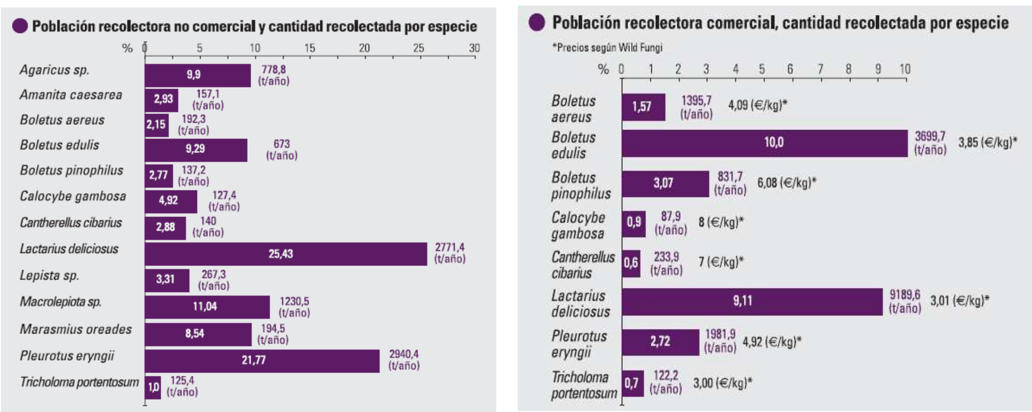


Fig. 1. Principales especies y cantidad recolectada, por población recolectora comercial y no comercial, en las áreas rurales de Castilla y León.

En lo referente al micoturismo, en Castilla y León el 54% de los alojamientos del ámbito rural de la región tienen clientes micoturistas, procedentes principalmente de Cataluña, País Vasco y Madrid. En conjunto, estas tres comunidades aportan casi el 80% de los turistas. Se ha estimado que unos 40.000 turistas visitan Castilla y León con el objetivo de recolección de setas (de Frutos *et al.*, 2011). Un estudio realizado en la comarca de Pinares de Soria-Burgos, muestra como los recolectores foráneos visitan la comarca tres veces al año y permanecen tres días por visita. El 94% de dichos recolectores utilizó algún servicio turístico de la comarca, el 35% restaurantes, el 37% hoteles y el 7% casas rurales (Martínez-Peña & García-Cid, 2003).

Recolector de setas en Pinar Grande. Se observa ganado equino pastando.

En cuanto a la micogastronomía, se estima que más de la mitad de los restaurantes del medio rural de Castilla y León incluyen setas silvestres en sus cartas y el 68% de ellos participarían en actividades de formación relacionadas con la gastronomía micológica (Martínez-Peña *et al.*, 2007). No obstante, se observa que el aprovisionamiento a través de empresas conserveras es todavía hoy muy bajo para la mayoría de las especies. Sirva de ejemplo el caso de los níscalos que entran en los restaurantes de los que sólo el 18% son comprados a empresas, siendo el resto compras directas a recolectores (42%) o recolección propia (40%) (Martínez-Peña *et al.*, 2007). Una aplicación estricta de la normativa legal existente por parte de las autoridades competentes podría corregir esta situación.

2 JUSTIFICACIÓN Y OBJETIVOS

El recurso micológico ha experimentado un aumento cuantitativo considerable, siendo necesario, en aras de la conservación y del adecuado aprovechamiento del recurso, que este incremento sea de la misma forma en términos cualitativos.

En economía, cuando un bien no tiene dueño, ni precio y es abudante se considera libre, no existiendo por tanto problemas para conseguirlo y llegando incluso a ser gratuito. En contrapartida a los anteriores se encuentran los bienes económicos o escasos. En un origen, las setas silvestres podían llegar a considerarse como un bien libre dada su abundancia y la poca demanda existente, pero en la actualidad sucede todo lo contrario. Podría decirse que las setas se han convertido en un bien escaso con una demanda en muchas ocasiones superior a la oferta, adquiriendo, por tanto, un valor muy elevado.

En el momento en que cualquier bien, en este caso las setas, presenta un elevado valor éste será sometido a una presión abusiva que, en el caso del recurso micológico, puede ocasionar la degeneración irreversible del mismo. Llegados a este punto es necesario diseñar acciones de ordenación encaminadas a la conservación y aprovechamiento sostenible del recurso micológico.

La recolección y el consumo de setas ha sido una constante en las zonas micófilas de España. Las primeras referencias de comercialización de setas se remontan varios siglos atrás. Con el paso del tiempo su venta se ha incrementado gracias a los avances en la tecnología que permitían el transporte no sólo del producto en conserva, sino también fresco a localizaciones cada vez más lejanas.

En las últimas décadas, la importancia del recurso micológico ha experimentado un incremento extraordinario, sobre todo en lo que se refiere a su comercialización y puesta en valor. La creación de empresas micológicas, el interés recreativo y social de la recolección de hongos así como el impulso otorgado al recurso desde las diferentes Administraciones Públicas, ha originado que, el micológico, se convierta en los últimos tiempos en un recurso de gran valor.

Empresa de trasformación de hongos silvestres comestibles en la década de los 50 ubicada en San Leonardo, en la Comarca de Pinares de Soria.

La situación existente en la actualidad es el resultado de un proceso de evolución relativamente corto pero intenso que ha llevado a situar al aprovechamiento micológico en un lugar preferente. Así, en este contexto en el que este recurso adquiere un elevado valor y la demanda del mismo aumenta de forma exponencial, cobra sentido la expresión “gestión micológica” entendida ésta como un conjunto de actuaciones encaminadas a la protección, planificación y explotación del recurso.

En términos generales, el presente trabajo pretende contribuir al establecimiento de una serie de criterios para la consecución de una gestión micológica adecuada y con éxito. Este concepto de gestión micológica es muy amplio, abarcando las fases de ordenación y regulación del recurso.

La tesis reúne tres publicaciones que abordan diferentes aspectos relacionados con la gestión del recurso micológico. Los objetivos pretendidos en estas publicaciones son:

1. Diseño de metodologías de muestreo que faciliten la obtención de la información sobre el recurso micológico preceptiva para una correcta gestión, así como la actualización periódica de la misma.
2. Determinación de criterios sólidos sobre los que fundamentar la elaboración, ejecución y revisión de planes de ordenación y regulación del recurso micológico.
3. Ampliar, en lo que pueda afectar a la gestión micológica, el conocimiento sobre la biología y ecología de las especies fúngicas de interés socioeconómico.

3 MATERIALES Y MÉTODOS

Todos los estudios se han desarrollado en el monte "Pinar Grande". A continuación se abordarán las características del citado monte así como una sucinta reseña a las diferentes unidades muestrales y otros elementos que han servido de base para el diseño experimental de los estudios incluidos en el presente trabajo.

3.1 La zona de estudio

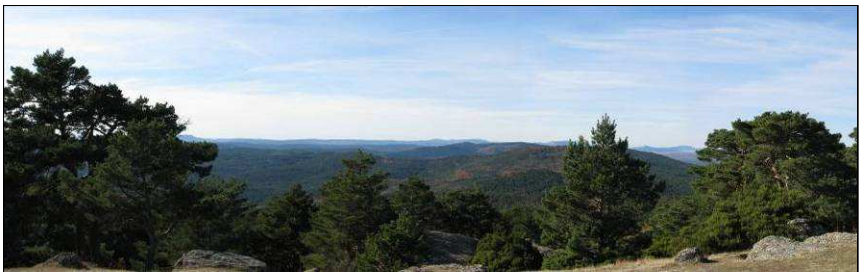
3.1.1 Localización, extensión y situación administrativa

El monte conocido como "Pinar Grande" es una gran masa arbolada de 12.533 ha, situada en la parte septentrional del Sistema Ibérico y representativa de los bosques de *Pinus sylvestris* L. de la Comarca de Pinares de Soria (Fig. 2).

Fig. 2. Localización geográfica del área de estudio.

Pinar Grande está constituido por los montes nº 172, 327 y 239 del Catálogo de Utilidad Pública de la provincia de Soria, pertenecientes al término municipal de Soria y cuya propiedad es compartida al 50% entre el Ayuntamiento de Soria y la Mancomunidad de los 150 pueblos de la Tierra de Soria.

3.1.2 Geomorfología



Panorámica desde Cabeza Alta (Pinar Grande, 1543 m.s.n.m.)

El área de estudio constituye una cuenca de orografía suave orientada de oeste a este, que varía altitudinalmente entre los 1.097 m.s.n.m. de la desembocadura del río Ebrillos, en el embalse de la Cuerda del Pozo y los 1.543 del pico de Cabeza Alta.

3.1.3 Hidrología

La hidrografía de Pinar Grande está representada por la cuenca del río Ebrillos, cuya superficie de 9.785 ha se encuentra incluida casi en su totalidad dentro de los límites del monte. En su recorrido, el Ebrillos desciende desde los 1.350 m de las Fuentecitas hasta los 1.097 m en la desembocadura, en el embalse de La Cuerda del Pozo. Además, se encuentran otras pequeñas cuencas de menor extensión y cursos estacionales que vierten sus aguas igualmente a dicho embalse cabecera del Duero.

Embalse de La Cuerda del Pozo a un elevado porcentaje de su capacidad.

Embalse de La Cuerda del Pozo en verano.

Dada la escasa pendiente, elevada densidad de drenaje y el caudal de esta cuenca, resulta frecuente encontrar zonas turbosas y trampales permanentes, además del encharcamiento o elevada humedad edáfica que presentan las cañadas de Pinar Grande durante buena parte del año.

3.1.4 Geología y litología

Río Ebrillos desbordado en primavera.

Río Ebrillos helado en periodo invernal.

El área de estudio se encuentra en la orla mesozoica que forman las estribaciones meridionales de la Cordillera Ibérica, en una zona de transición entre la llanura del Duero al sur y el macizo de Urbión al norte (IGME, 1998).

La litofacies preponderante corresponde al Cretácico Inferior, Facies Weald (Grupo de Urbión), formada por alternancia de cuarzoarenitas, cuarzoarenitas conglomeráticas y arcillas cuarzoarenitosas generalmente rojas, cuya potencia se estima en 250 y 300 m.

Igualmente tiene una importante representación la Facies Purbeck-Weald del Cretácico Inferior y Jurásico Malm (Grupo de

Oncala), formada por cuarzoarenitas conglomeráticas sobre alternancia de cuarzoarenitas y arcillas cuarzoarenitosas finas de color verde grisáceo. La potencia se estima en 200 m.

En las cañadas de Pinar Grande, por estar ligadas a cursos temporales y permanentes, predominan los depósitos aluviales del Cuaternario.

3.1.5 Edafología

La descripción de las unidades de suelos de Pinar Grande se ha basado en el Mapa de Suelos de Castilla y León (E 1:500.000) de García Rodríguez (1988), así como en los datos edafológicos correspondientes al estrato de las Cañadas y en otros trabajos que han estudiado perfiles de suelos en Pinar Grande (Ministerio de Agricultura, 1967; 1969; Instituto Nacional de Investigaciones Agrarias, 1991; 1996).

Los suelos son pardo ácidos, ferrilúvicos o ferriargilúvicos, con pH marcadamente ácido (entre 4 y 5), textura arenosa a franca-arenosa, poca capacidad de retención de agua y escasa fertilidad.

3.1.6 Clima

En Pinar Grande se encuentra una estación meteorológica, la nº 2.008 "El Amogable", perteneciente a la red de la Agencia Estatal de Meteorología. Está situada a 1.150 m de altitud, en el centro de la cuenca del río Ebrillos, 02º 57' 07'' W 41º 51' 30'' N. Se trata de una estación termopluviométrica con registros desde 1979, cuyo resumen de datos se detalla en la Tabla 1.

Tabla 1. Variación mensual de las variables climáticas de la estación meteorológica de "El Amogable", correspondiente al periodo (1979-2003).

Meses	P (mm)	T (ºC)	M_ (ºC)	m_ (ºC)	M (ºC)	m (ºC)
Enero	86,5	1,9	6,9	-3,1	19,0	-17,0
Febrero	83,9	2,7	8,6	-3,2	21,8	-22,0
Marzo	49,0	4,9	12,3	-2,3	23,9	-14,0
Abril	87,7	6,1	12,8	-0,5	26,3	-10,0
Mayo	84,9	9,7	16,8	2,6	30,0	-8,0
Junio	65,0	14,0	22,8	5,2	35,0	-3,1
Julio	39,3	17,4	27,8	7,3	37,0	-3,0
Agosto	29,8	17,3	27,7	6,9	38,0	-5,0
Septiembre	45,1	13,8	22,9	4,7	34,0	-5,1
Octubre	86,6	9,5	16,6	2,3	31,0	-7,4
Noviembre	85,5	5,3	11,2	-0,5	24,0	-14,0
Diciembre	121,5	2,9	7,8	-2,0	19,0	-16,0

* **P**: precipitación, **T**: temperatura media, **M_**: temperatura media de las máximas, **m_**: temperatura media de las mínimas, **M**: temperatura máxima absoluta, **m**: temperatura mínima absoluta.

Fitoclimáticamente, Pinar Grande pertenece al subtipo $VI(IV)_2$ nemoromediterráneo genuino (Allué, 1990). La precipitación anual media, según los datos de la estación de “El Amogable”, es de 865 l/m², de los que 69 l/m² se producen en julio y agosto y 132 l/m² en septiembre y octubre. Los veranos son frescos, siendo julio el mes más caluroso con una temperatura media 17,4 ºC. El periodo de helada segura comienza en noviembre y termina en abril, si bien, también son frecuentes las heladas tempranas y tardías de otoño y primavera (Fig. 3).

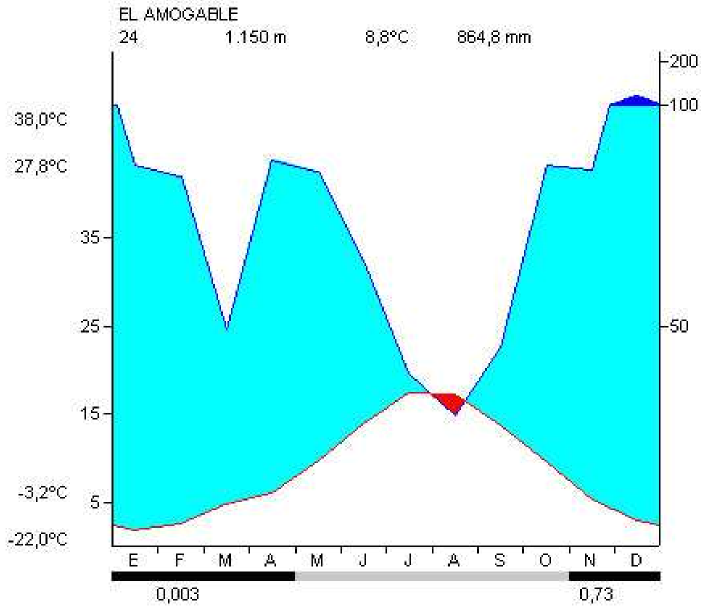
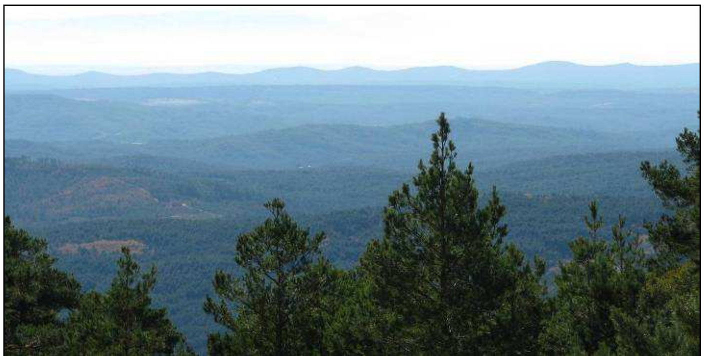


Fig. 3. Diagrama climático de Walter & Lieth. La duración del periodo de sequía es de un mes, desde finales de julio hasta finales de agosto.

3.1.7 Vegetación



Panorámica de Pinar Grande y parte de la Comarca de Pinares de Soria.

La superficie arbolada total de Pinar Grande es de 12.068 ha. Los pinares de *P. sylvestris* constituyen el 70% del total de la masa y aparecen preferentemente en los fondos de los valles (cañadas) y en las laderas de umbría; lugares en los que habita de forma monoespecífica. Las masas de *Pinus pinaster* Ait. ocupan las zonas de divisoria y laderas de solana. Ambas especies se mezclan, en mayor o menor grado, en las zonas de transición. La siguiente especie en orden de importancia es *Quercus pyrenaica* Willd., pudiendo alcanzar ocasionalmente cierta abundancia en algunas zonas, aunque generalmente forma parte del sotobosque en forma arbustiva.

Las masas de *Pinus pinaster* ocupan las zonas de divisoria y laderas de solana.

El sustrato arbustivo está constituido por brezales mesohigrófilos de *Erica vagans* L., *Erica arborea* L. y otras especies como *Crataegus monogyna* Jacq., *Arctostaphyllos uva-ursi* (L.) Spreng. y a destacar, la presencia de *Myrica gale* L., de interés geobotánico (Lucas & Barrio, 1996).

Brezales mesohigrófilos de *Erica vagans*.

Los pastizales más productivos se localizan en las zonas de vaguada y están constituidos por herbáceas edafohigrófilas de relativamente alta producción pascícola.

De cara a poder establecer de una forma coherente y fundada unos criterios para la gestión del recurso micológico, es imprescindible contar con la mayor cantidad de información sobre el comportamiento de cada una de las especies micológicas de interés en cada formación vegetal.

En la actualidad se está avanzando en la idea de una gestión para el recurso micológico de una forma coordinada y considerando la totalidad de formaciones vegetales productoras de setas diferentes según la zona geográfica que se estudie (Martínez-Peña *et al.*, 2011c). Este autor ha establecido 19 estratos diferentes entre pastizales, matorrales y bosques, que se reducen a 12 agrupaciones de cara a facilitar la inventariación. Los bosques estudiados ampliamente en la presente tesis son los denominados como “pinares montanos higrófilos silicícolas de *Pinus sylvestris* L. productores de *Boletus* gr. *edulis*”.

3.1.8 Micocenosis

El estudio de la comunidad de hongos a partir de la red de parcelas permanentes de Pinar Grande ha llevado a determinar 119 especies de hongos macromicetes epigeos, todos ellos pertenecientes a la división Basidiomycota excepto

Fuligo septica (L.) F.H. Wigg. que forma parte de Amoebozoa (Myxogastria) (Martínez-Peña, 2009).

En total, en este estudio se han registrado 51 géneros, de los que *Russula, Cortinarius, Tricholoma, Amanita, Lactarius, Collybia, Cystoderma, Hebeloma, Mycena* y *Suillus,* aportaron más del 50% de las especies determinadas (Fig. 4).

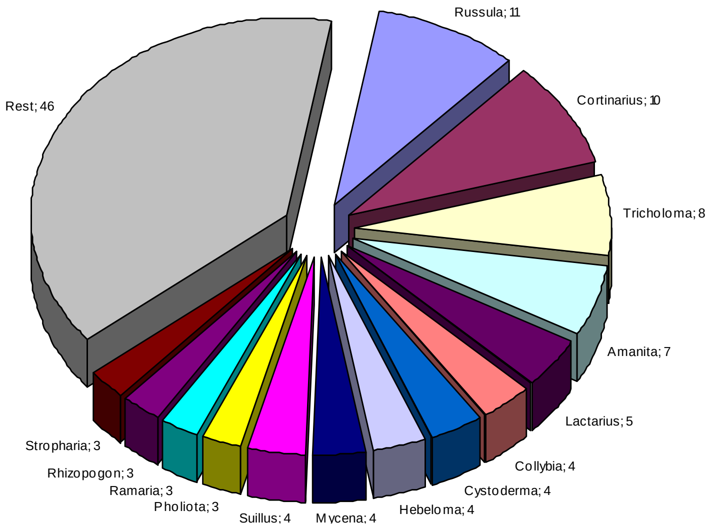


Fig. 4. Relación de géneros de macromicetes epigeos otoñales con el número de taxones aportado, registrados entre 1995 y 2004 en Pinar Grande.

En la Figura 5 se representan las producciones medias registradas de carpóforos de *Boletus edulis* y *Lactarius deliciosus* en Pinar Grande en las campañas 1995 a 2008 por clase de edad (Martínez-Peña, 2009), observándose claramente la tendencia productiva de ambas especies con el paso del tiempo. *Boletus edulis* es una especie cuya máxima producción de carpóforos se produce en pinares de edad media, mientras que la máxima producción de níscalos se produce en masas jóvenes y de edad avanzada, siendo menor en pinares de edad media.

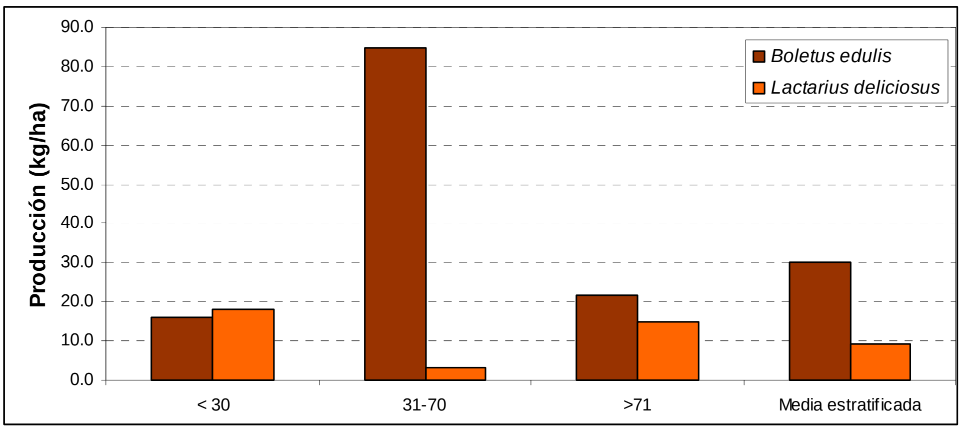


Fig. 5. Producción bruta media por clases de edad y estratificada en kg/ha y año de *Boletus edulis* y *Lactarius deliciosus.*

3.1.9 Fauna

Según los datos de la octava revisión del proyecto de ordenación de Pinar Grande realizada en 1996 por (Lucas & Barrio, 1996), se estima una carga ganadera media de 399 vacas de aptitud cárnica y 2.230 ovejas, que pastan libremente por una superficie de 6.500 ha. Por tanto, la carga es de 6 vacas/km² y 34 ovejas/km², equivalente a 12 UGM/km².

Respecto a la fauna cinegética presente en el monte, destaca la presencia de corzo (*Capreolus capreolus* L.) y jabalí (*Sus scrofa* L.). La población de ciervo (*Cervus elaphus* L.) es inferior pero en notable expansión. Las tres especies anteriores tienen un marcado carácter cinegético y afectan a la producción de hongos (micófagos). Su gestión cinegética está integrada en los planes de Ordenación de la Reserva Regional de Caza de Urbión. Existen otras especies representativas del monte como son: zorro (*Vulpes vulpes* L.), gato montés (*Felis silvetris* Schreber), paloma torcaz (*Columba palumbus* L.), ratonero (*Buteo buteo* L.), búho chico (*Asio otus* L.), etc.

3.1.10 Estado forestal

La ordenación forestal de Pinar Grande fue aprobada por R.O. de 13/11/1907 iniciándose su ejecución en el año 1909-1910 (Lucas & Barrio, 1996). Se adoptó el método de ordenación por tramos periódicos permanentes, tratamiento de masas regulares (Madrigal, 1994). Se fija un turno de corta de 100 años y un periodo de regeneración de 20 años.

Repoblado joven en Pinar Grande.

Corta de regeneración en Pinar Grande.

Las cortas de regeneración aplicadas en Pinar Grande han evolucionado desde entresacas con pastoreo indiscriminado del ganado, en el siglo pasado y principios de este siglo, a cortas por aclareo sucesivo uniforme con diseminación natural sin movimiento del suelo y, en los últimos 40-50 años, a cortas a hecho con movimiento del suelo y siembras. Actualmente no se descarta la realización de cortas por aclareo sucesivo, en las áreas más sensibles desde el punto de vista paisajístico o donde las cortas a hecho pudieran ocasionar efectos negativos sobre el medio (Lucas & Barrio, 1996).

El aprovechamiento principal del monte corresponde a la madera, que se vende en pie con señalamiento previo y liquidación final tras cubicación.

Los aprovechamientos cinegéticos son gestionados por la Reserva Regional de Caza de Urbión, que comprende una superficie de 100.023 ha. Pinar Grande forma parte de los cuarteles XI y XII de dicha reserva, con un total de 15.243 ha.

En los últimos años se ha avanzado enormemente en la regulación de la recolección a nivel regional. Desde el otoño de 2011, el monte Pinar Grande está incluido dentro de las actuaciones de regulación del aprovechamiento micológico del proyecto Myas RC de la Junta de Castilla y León, en la Unidad de Gestión Administrativa "Urbión" de la provincia de Soria (www.myasrc.es). Para poder recoger setas es necesario obtener una licencia de recolector cuyo precio varía por la cantidad que permite recolectar y por el lugar de procedencia del recolector. Esto supone una fuente de ingresos que puede revertir en mejoras en el monte y que, en cualquier caso, ejerce una inestimable labor para la conservación y adecuado aprovechamiento del recurso micológico. La realidad es que el aprovechamiento de los hongos está hoy en día muy extendido, tanto por el valor comercial que suponen las recolecciones, como por el número creciente de turistas que acuden a estas zonas atraídos por su riqueza micológica.


Labores de apilamiento de la madera en rollo para su posterior transporte.

Se estima que el 43% del total de recolectores que visitan Pinar Grande son turistas, siendo el 42% de estas visitas con fines comerciales y el 58% restante por interés recreativo. La presión recolectora estimada en este monte oscila entre los 2 y 25 recolectores/km^2 y día en años de mala y buena producción respectivamente que recolectan una media de 4,3 kg/día de *B. edulis* (Martínez-Peña, 2003).


Recolector en Pinar Grande.

3.2 Red de unidades muestrales

En Pinar Grande se han establecido diferentes redes de unidades muestrales persiguiendo determinados objetivos concretos, aunque todos ellos dirigidos a un objetivo común: avanzar en el conocimiento del recurso micológico.

3.2.1 Parcelas permanentes valladas

En 1995, el Departamento de Investigación Forestal de Valonsadero estableció en el monte Pinar Grande un dispositivo experimental de parcelas para el estudio de la influencia de la edad de la masa en la producción de carpóforos de hongos silvestres comestibles en masas de *Pinus sylvestris*. La cantidad de información recogida con esta red de parcelas es tan amplia que ha permitido caracterizar no sólo la producción de hongos, sino también la diversidad, la ecología y la biología de los mismos, dando lugar a numerosas publicaciones (Martínez-Peña, 2003; Ortega-Martínez & Martínez-Peña, 2008; Martínez-Peña, 2009; de Frutos *et al.*, 2009; Ortega-Martínez *et al.*, 2011; Martínez-Peña *et al.*, 2011a).

El diseño experimental aplicado consistió en un muestreo aleatorio estratificado por clases de edad del arbolado (de Vries, 1986). La ordenación por tramos periódicos permanentes conduce a un mosaico de masas regulares, organizadas en el espacio y el tiempo (Madrigal, 1994), lo que permitió diseñar y controlar la superficie de la estratificación. Dicha estratificación se justifica por ser la edad de la masa forestal, un factor condicionante de la composición específica de las comunidades de hongos ectomicorrícicos (Le Tacon *et al.*, 1984; Garbaye & Le Tacon, 1986; Strullu, 1991).

Las clases de edad de la masa de *P. sylvestris* consideradas en la estratificación fueron cinco, en coherencia con los cinco tramos de ordenación forestal aplicados en este monte (Tabla 2). Pinar Grande está organizado en cinco secciones, divididas en cinco cuarteles de ordenación, lo que suma un total de 130 tramos de ordenación, los cuales fueron considerados homogéneos en cuanto a clases de edad de la masa forestal y tratamientos selvícolas.

Tabla 2. Características de las clases de edad de la masa forestal consideradas en la estratificación para el estudio de la producción de carpóforos.

CLASE	EDAD 1995	TRAMO	METODO DE REGENERACIÓN FORESTAL	SUP (ha)
1	≤15 años	IVb	Corta a hecho	52,82
2	16-30 años	III	Corta a hecho	350,80
3	31-50 años	II	Aclareo sucesivo uniforme	339,11
4	51-70 años	I	Aclareo sucesivo uniforme.	459,27
5	>70 años	V y IVb	Regeneración natural o entresaca por huroneo	547,58
			TOTAL	1749,59

Con el fin de reducir la variabilidad espacial y temporal de la producción micológica, se redujo el estudio a un área de 1.750 hectáreas, denominada "Las Cañadas de Pinar Grande", donde las masas de *P. sylvestris* son monoespecíficas y se desarrollan sobre zonas de suelos y fisiografía homogéneos. El área de "Las Cañadas" fue definida como aquella de pendiente menor o igual al 5%, comprendida en la cuarta parte inferior de todas las laderas de la red hidrográfica de Pinar Grande. Se trata, por tanto, de estaciones forestales de *P. sylvestris* con humedad edáfica elevada, lo que *a priori* se consideró como uno de los hábitats más favorables para la fructificación de macromicetes en estas masas (Fernandez-Toirán, 1994; Martínez-Peña, 2003).

Parcela vallada permanente de muestreo ubicada en las "cañadas" de Pinar Grande.

En el área de "Las Cañadas" de Pinar Grande, una vez estratificada por clases de edad, se establecieron aleatoriamente 18 unidades muestrales.

El número de repeticiones por clase de edad fue de tres, excepto para la clase de edad nº 5 (>70 años), donde se duplicó el número de repeticiones al tratarse de masas de mayor heterogeneidad como consecuencia de las características de su regeneración (Tabla 2).

Las unidades de muestreo se replantearon sobre el terreno, mediante estaquillas de madera, con una dimensión de 35x5 m. El tamaño y forma de las parcelas se adoptó siguiendo las recomendaciones de estudios previos (Sjöblom *et al.*, 1979; Kalamees & Silver, 1988; Ohenoja, 1989; Fernandez-Toirán, 1994), que utilizan formas rectangulares con una superficie mínima de 100 m^2.

Las parcelas se vallaron con malla cinegética de 2 m de alto, para evitar el consumo de carpóforos por el ganado y la fauna silvestre, así como la presión de los recolectores. Anualmente, durante el mes de agosto, se realiza una siega del pastizal existente en las parcelas, con el fin de facilitar la detección posterior de los carpóforos en los muestreos de otoño.

Durante los meses de otoño se recolectan todos los carpóforos epigeos, de tamaño de sombrero superior a 1 cm, observados en cada parcela. Algunas especies, particularmente de los géneros *Mycena* y *Marasmius*, cuyos carpóforos en la madurez pueden ser inferiores a 1 cm, no fueron recolectados por su fragilidad y la dificultad de manejo que entrañan.

3.2.2 Transectos permanentes

El diseño experimental consiste en tres unidades muestrales por clase de edad y estrato, es decir, se establecieron tres transectos en masas maduras (> 71 años), tres en masas de 31 a 70 años y tres más en masas jóvenes (16 a 30 años), no estableciéndose ninguno en masas menores de 15 años por la ausencia de producción de las especies de interés, todo ello para el estrato de "Las Cañadas" repitiéndose para el estrato de ladera. Así, y teniendo en cuenta el diseño anterior se instalaron un total de 18 transectos, nueve en "Las Cañadas" y nueve en laderas. Cada uno de estos transectos cuenta con una longitud aproximada de 330 m.

Transecto permanente en "Las Cañadas" de Pinar Grande.

Los transectos constan de una serie de árboles que se seleccionan siguiendo, como se ha comentado y en la medida de lo posible, las curvas de nivel a lo largo de una longitud de unos 333 metros. Cada uno de los árboles que forma parte del transecto se numera con spray de modo que desde cada uno de estos se pueda ver el siguiente y el anterior, ya que en estratos más jóvenes (mayor espesura) o con abundante sotobosque la visibilidad para seguir el recorrido es reducida.

Además de numerar los árboles, se toman las coordenadas UTM de cada árbol mediante GPS y se miden las distancias existentes entre cada par de árboles consecutivos, necesarias para cálculos posteriores.

Muestreador en un transecto permanente.

Los procedimientos de muestreo planteados son principalmente dos. En uno se reservan los carpóforos y en el otro no. El primero de los artículos incluidos en el presente trabajo aborda ampliamente el muestreo de transectos con reserva de carpóforos. El segundo método es más sencillo y se reduce a la recolección de todos los ejemplares avistado en el recorrido con un ancho de banda prefijado.

3.2.3 Recorridos de muestreo de presión recolectora

Con objeto de aprovechar los días de visita al monte para llevar a cabo los muestreos referidos en apartados anteriores, se establecieron recorridos fijos entre unidades muestrales que permitieron estimar la presión recolectora.

Vehículo de recolectores estacionado en los laterales de una pista forestal en Pinar Grande.

En el recorrido entre dichas unidades muestrales se registran los vehículos de los recolectores (procedencia-matrícula) que se encuentran estacionados en los laterales de las pistas forestales. Así, partiendo de la longitud total de este recorrido que asciende a 29,5 km. y de la longitud total de pistas consideradas accesibles para turismos en el monte “Pinar Grande” (96,5 km aprox.), es posible determinar la presión recolectora en dicha zona (Martínez-Peña, 2003).

La presión recolectora en años productivos puede llegar a ser muy elevada.

Para convertir el número de vehículos registrado a número de visitas se considera que en cada vehículo de procedencia local viajan 2,02 recolectores y en los de procedencia foránea 2,57 recolectores (García-Cid, 2002).

4 RESULTADOS

En el presente apartado se detallan los resultados obtenidos en las publicaciones presentadas en la tesis. Los temas publicados en esta tesis complementan o son complementados por otros estudios realizados con anterioridad. Posteriormente se reseñarán datos de algunos de ellos de interés para el seguimiento de la presente tesis.

La producción media otoñal de carpóforos de las masas de *Pinus sylvestris* estudiadas, se ha estimado en 151,77 ± 12,54 kg/ha arbolada (Martínez-Peña, 2009). Particularizando a las especies fúngicas analizadas, *Lactarius deliciosus* registró una producción de casi 10 kg/ha y año. La producción de *Boletus edulis* superó los 40 kg/ha arbolada y año, lo que la convierte en la especie fúngica de la zona de estudio que mayor biomasa aporta respecto del total de macromicetes (26,6%), además de ser una de las especies cuya producción presenta una mayor regularidad interanual (Martínez-Peña, 2009).

Estas producciones globales pueden ser desglosadas por clases de edad, gracias al diseño experimental de los muestreos. Las producciones en cada uno de estos intervalos de edad es diferente, variando en función de la especie fúngica. *Lactarius deliciosus* presenta el máximo absoluto de producción (18,4 kg/ha y año) en edades del arbolado comprendidos entre los 16 y 30 años, siendo la mayor de 71 años la segunda clase más productiva (16,3 kg/ha y año). En cambio, *B. edulis*, registra sus máximos de producción en las clases centrales de edad con 41 y 70 kg/ha y año en masas de 31 a 50 años y 51 a 70 años, respectivamente. Agrupando en tres clases de edad (Figura 5) se observa que el tramo central de edad se desmarca considerablemente del resto (Martínez-Peña, 2009).

PROCEDIMIENTO DE MUESTREO PARA LA ESTIMACIÓN DE LA PRODUCCIÓN DE CARPÓFOROS DE HONGOS SILVESTRES COMESTIBLES DE INTERÉS SOCIOECONÓMICO

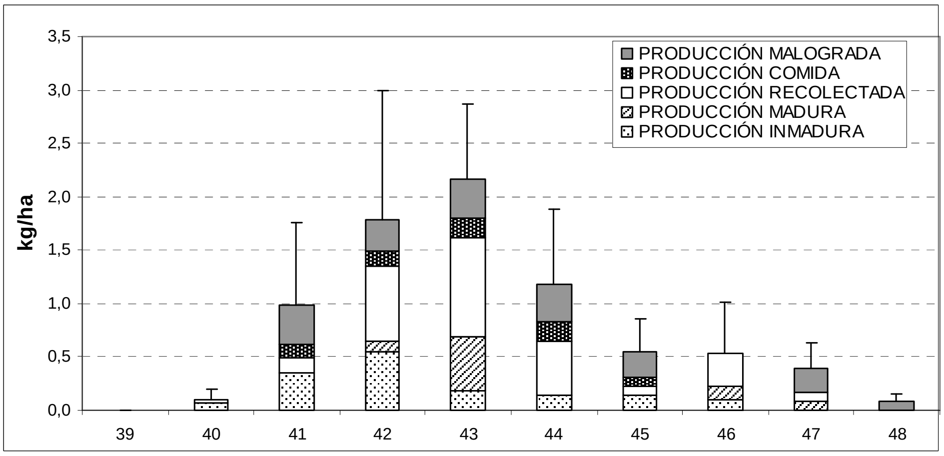
Mediante un método de muestreo basado en transectos permanentes en el que se reservan los carpóforos de un muestreo al siguiente, es posible desglosar la producción bruta en: producción recolectable (desglosada a su vez en inmadura y madura), producción recolectada, producción consumida por fauna y producción malograda según la siguiente expresión (Ortega-Martínez & Martínez-Peña, 2008):

$$P_{Bi} = p_i + P_i + R_i + G_i + M_i$$

Donde, P_{Bi} es la producción bruta estimada en la semana i; p_i es la producción inmadura recolectable estimada en la semana i; P_i es la producción madura recolectable estimada en la semana i; R_i es la producción recolectada en la semana i; G_i es la producción consumida por fauna en la semana i y M_i es la producción malograda (pisados, parasitados, arrancados, senescentes, etc.) en la semana i. A su vez, cada uno de estos sumandos se subdivide en una serie de componentes.

Aplicando la metodología de muestreo anterior se obtiene, para *B. edulis*, la siguiente distribución de la producción bruta: Un 24% resulta recolectada, un 7% la consume el ganado, el 26% resulta malograda por diferentes causas y un 43%

corresponde con la producción recolectable, de la cual, un 15% es considerada como madura.



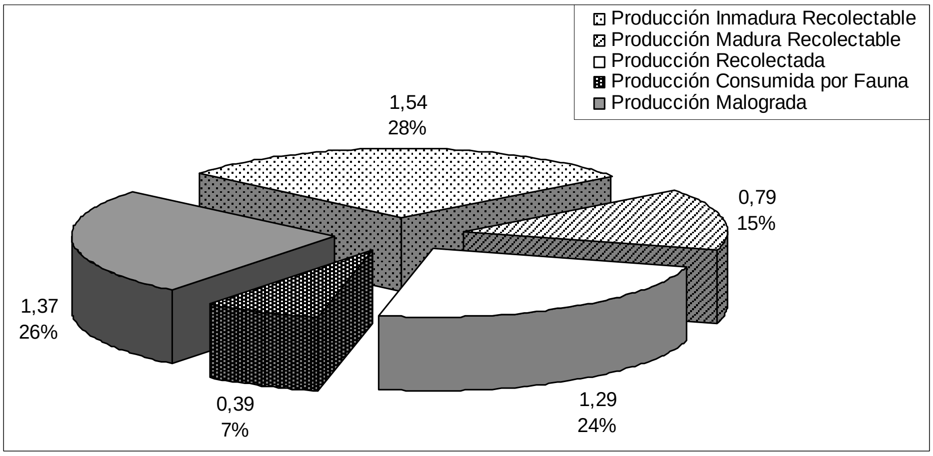


Fig. 6. En el gráfico superior, distribución de la producción bruta semanal de *Boletus edulis* en Pinar Grande según semanas de muestreo. En el gráfico inferior, distribución porcentual de la producción bruta media de *B. edulis* en Pinar Grande.

En la Tabla 3 se desglosa la producción bruta calculada semanalmente para *B. edulis.* Se puede observar que, únicamente las semanas 43, 46 y 47 cuentan con una producción madura recolectable lo suficientemente elevada como para garantizar la regeneración del hongo (considerando óptimo para la regeneración un porcentaje superior al 20% de la producción bruta).

Tabla 3. Porcentaje semanal de cada tipo de producción considerado para *Boletus edulis* en Pinar Grande.

SEM	p_i (%)	P_i (%)	R_i (%)	G_i (%)	M_i (%)	PRODUCCIÓN BRUTA (kg/ha)
39	-	-	-	-	-	0 ± 0
40	69	0	31	0	0	0,09 ± 0,09
41	36	0	14	13	37	0,99 ± 0,77
42	30	6	39	8	16	1,78 ± 1,22
43	8	24	43	9	17	2,17 ± 0,69
44	12	0	43	15	30	1,19 ± 0,7
45	27	0	15	14	45	0,55 ± 0,31
46	19	23	58	0	0	0,54 ± 0,47
47	0	20	24	0	56	0,4 ± 0,24
48	0	0	0	0	100	0,08 ± 0,08

Por otra parte, mediante el método de muestreo referido es posible obtener las distancias perpendiculares o anchos de banda en el muestreo. Para *B. edulis* se obtuvo que, en una banda de dos metros a cada lado del transecto son localizados la totalidad de ejemplares presentes por lo que el coeficiente de detectabilidad (CD) es 1. En cambio, en distancias superiores a los ocho metros no se detecta ningún ejemplar (CD=0). A partir de estas asunciones fue posible establecer la fórmula de cálculo del coeficiente de detectabilidad de *B. edulis* en función del ancho de banda. El coeficiente de detectabilidad global para *B. edulis* para un ancho de banda de 8 m a cada lado es de 0,53 y responde a la siguiente función de detectabilidad:

$$CD = (1{,}04871 - 0.128589 * DP)^2 \qquad (R^2 = 98\%)$$

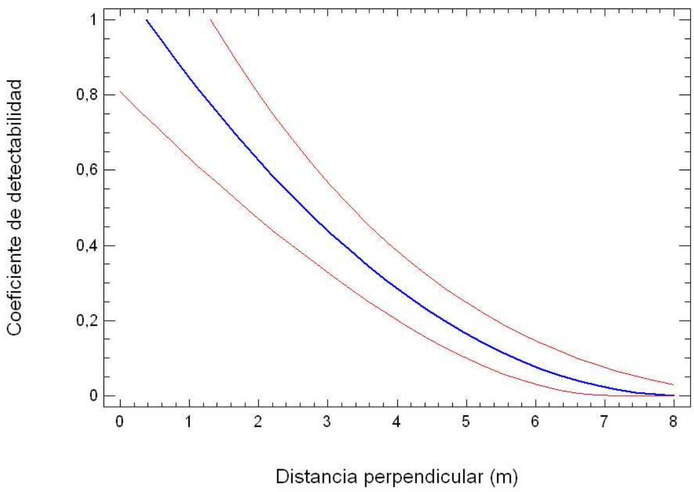


Fig. 7. Función de detectabilidad para *Boletus edulis* en Pinar Grande para un ancho de banda de 8 m.

INFLUENCIA DE LA EDAD DE LA MASA EN EL DESARROLLO DE CARPÓFOROS DE HONGOS ECTOMICORRÍCICOS EN BOSQUES DE PINUS SYLVESTRIS

La producción de hongos en función de las clases de edad no sólo no es constante en peso, sino que tampoco lo es en número de ejemplares ni en lo que cada uno de estos aporta en peso a la producción total. El peso de un ejemplar de *B. edulis* es claramente diferente en las tres clases de edad consideradas, presentando el máximo en la primera clase de edad (127 g y 6,8 cm de diámetro), decreciendo hasta su mínimo en la segunda (68 g y 4,7 cm) y volviendo a crecer hasta un máximo relativo en la tercera clase de edad (79 g y 4,3 cm). La tendencia marcada por *B. edulis* es seguida de la misma forma por *L. deliciosus* presentando, el máximo absoluto en la primera clase de edad (48 g y 7,4 cm), decreciendo en la segunda (20 g y 5,8 cm) y también en la tercera clase de edad (21 g y 5,3 cm) (Ortega-Martínez *et al.*, 2011).

Tabla 4. Estadísticas descriptivas del peso y diámetro de carpóforos de *Lactarius deliciosus* y *Boletus edulis* recolectados semanalmente entre los años 1995 y 2008 en masas de *Pinus sylvestris*.

		Peso de los carpóforos (g)						Diámetro de los carpóforos (cm)		
		< 30		31-70		> 71		< 30	31-70	> 71
L. deliciosus	Frecuencia (carpóforos analizados)	73		36		149		35	6	48
		peso	Log (peso)	peso	Log (peso)	peso	Log (peso)			
	Media	47.4	1.7	20.3	1.3	21.0	1.3	7.4	5.8	5.3
	Mediana	38.0	1.6	21.5	1.3	17.3	1.2	7.0	6.5	5.0
	Desviación standard	35.5	1.6	10.4	1.0	13.1	1.1	2.5	1.6	1.8
B. edulis	Frecuencia	138		721		270		124	675	218
	Media	126.8	2.1	68.1	1.8	78.9	1.9	6.8	4.7	5.3
	Mediana	92.5	2.0	40.0	1.6	60.0	1.8	6.0	4.0	5.0
	Desviación standard	125.9	2.1	83.5	1.9	65.1	1.8	3.8	2.3	2.5

En las siguientes figuras se puede observar la existencia de diferencias significativas entre las diferentes clases de edad.

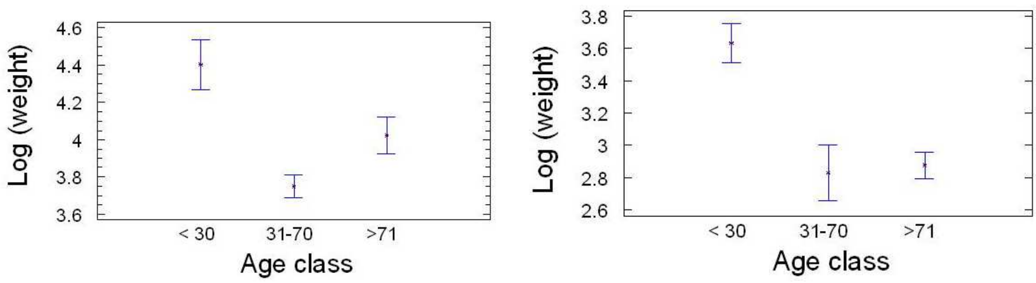


Fig. 8. Peso medio de un carpóforo de *Boletus edulis* (derecha) y *Lactarius deliciosus* (izquierda) por clase de edad. En ordenadas: el peso del carpóforo con transformación logarítmica, con representación de los intervalos de Tukey al 95%. En abcisas: clases de edad (1: ≤30 años, 2: 31-70 años, 3: >71 años).

ESTIMACIÓN MEDIANTE EL MÉTODO DEL COSTE DE VIAJE DE LOS BENEFICIOS SOCIALES DE LA RECOLECCIÓN RECREATIVA DE HONGOS SILVESTRES COMESTIBLES

Como se indica en apartados anteriores, la recolección de setas origina un gran interés entre la población. Este interés social puede ser cuantificado por diversos métodos económicos. Aplicando el método del coste de viaje puede obtenerse la curva de demanda del recurso y, a partir de esta, calcular el excedente del consumidor anual. Para el monte Pinar Grande, entre los años 1997 y 2005, se obtiene un valor medio de 21,41 € por coche (10,49 € por persona adulta) y varía entre 12,59 € por coche (6,05 € por persona) en 2005 y 28,73 € por coche (14,91 € por persona) en 2001. Los valores unitarios han sido calculados en base al número de recolectores por vehículo recogidos en García-Cid (2002), cuya media para el periodo de estudio asciende a 2,28 recolectores (de Frutos *et al.*, 2009).

Tabla 5. Excedente del consumidor (MCS) estimado para recolección recreativa de hongos silvestres en Pinar Grande.

Año	Coste de viaje real ponderado	Coste de viaje máximo	MCS (€)
1997	27.29	356.82	18.79
1998	19.88	356.82	27.30
1999	27.30	356.82	21.32
2000	25.64	356.82	18.05
2001	25.39	356.82	28.73
2002	25.32	356.82	22.55
2003	24.50	356.82	28.04
2004	26.20	356.82	15.39
2005	18.73	356.82	12.59
Media			**21.41**

La Tabla 6 recoge los estimadores mediante míninos cuadrados del modelo de demanda. La expresión que responde al modelo de demanda, calculada anualmente entre 1997 y 2005, es la siguiente:

$$Ln(VI_i) = \alpha + \beta_1 * {}^{1}\!/_{TC_i} + \beta_2 * GDPpc_i + \beta_3 * MS_i + \varepsilon_i$$

Donde, VI es la tasa de visitas definida como visitas por cada 1000 habitantes; TC es el coste del viaje calculado entre la capital y el área de estudio; GDPpc es el Producto Interior Bruto per cápita y MS es el número de sociedades micológicas existentes en la zona.

Tabla 6. Resumen del modelo de demanda y parámetros. Estimaciones basadas en mínimos cuadrados ordinarios.

AÑO	A				β1				β2				β3			
	Valor	Error Estand.	t-valor	Sig (99%)	Valor	Error Estand.	t-valor	Sig (99%)	Valor	Error Estand.	t-valor	Sig (99%)	Valor	Error Estand.	t-valor	Sig (99%)
1997	-3.623	1.234	-2.937	SI	34.692	5.597	6.198	SI	0.045	0.086	0.520	NO	-0.08	0.088	-0.86	NO
1998	-6.084	1.344	-4.528	SI	48.803	6.591	7.405	SI	0.204	0.095	2.159	SI (*)	0.06	0.116	0.48	NO
1999	-4.276	1.130	-3.783	SI	46.242	7.112	6.502	SI	0.078	0.077	1.017	NO	-0.01	0.101	-0.08	NO
2000	-4.868	1.331	-3.658	SI	47.509	7.296	6.511	SI	0.087	0.086	1.001	NO	0.06	0.126	0.51	NO
2001	-5.244	1.398	-3.750	SI	54.197	5.935	9.132	SI	0.134	0.073	1.849	SI**	-0.04	0.073	-0.59	NO
2002	-5.972	1.148	-5.201	SI	52.924	7.011	7.549	SI	0.173	0.066	2.632	SI	-0.07	0.088	-0.78	NO
2003	-4.481	1.366	-3.281	SI	50.065	7.947	6.300	SI	0.084	0.075	1.122	NO	0.00	0.094	-0.03	NO
2004	-5.179	1.202	-4.309	SI	48.975	5.974	8.198	SI	0.072	0.061	1.179	NO	0.08	0.060	1.34	NO
2005	-3.704	0.856	-4.327	SI	38.799	12.754	3.042	SI (*)	-0.07	0.285	-0.26	NO	-0.42	0.410	-1.01	NO

(*) Significativo al 95% (**) Significativo al 90%

Únicamente el número de visitas por cada 1.000 habitantes en la zona influye significativamente en los modelos de demanda. Los otros coeficientes considerados no presentan esta significatividad. La renta per cápita únicamente fue significativa tres años de los nueve estudiados y el número de sociedades micológicas no influía de manera significativa ningún año.

Entre los factores explicativos del modelo del excedente del consumidor, la producción de *B. edulis* es la que presenta una influencia significativa. En cambio, otras variables como el coste de la gasolina no fueron significativas en el modelo, es decir, no influyen en el bienestar del los recolectores. Un recolector en óptimas condiciones de información sólo se desplazará en caso de que las expectativas de recolección sean altas. Esta situación se hace más patente en recolectores recreativos cuyo objetivo fundamental es recolectar hongos, aunque su valor sea bajo. En cambio los recolectores comerciales acudirán al monte aunque las expectativas de recolección sean menores pero el precio de la cosecha sea alto.

En la Tabla 7 se detallan los resultados de la estimación por el método de mínimos cuadrados de los factores explicativos del modelo del excedente del consumidor.

$$Ln(MCS_t) = \alpha' + \beta'_1 * BEFP_t + \beta'_2 * BEFP_{t-1} + \beta'_3 * CP_t + \varepsilon_i$$

Donde, MCS es el excedente del consumidor, BEFP es la producción estimada de *B. edulis* y CP es el coste del combustible.

Tabla 7. Resumen del modelo del excedente del consumidor y parámetros. Estimaciones basadas en mínimos cuadrados ordinarios.

Resumen del modelo	Valor	Parámetros	Valor	Error estandard	t-valor	Sig (95%)
R	0.843	**α´**	3.207	0.633	5.064	SI
R2	0.711	**β1´**	0.009	0.003	2.643	SI
Adjusted R^2	0.538	**β2´**	0.001	0.003	0.238	NO
F	4.113	**β3´**	-0.362	0.764	-0.827	NO
Sig (95%)	SI (*)					
Durbin-Watson	2.748					

(*) Significativas al 90%.

5 DISCUSIÓN

Los estudios y trabajos de investigación son necesarios de cara a establecer metodologías, patrones y criterios para abordar con éxito la gestión micológica.

Todos estos trabajos tratados de manera individual tienen escasa utilidad para la gestión, pero si se complementan unos con otros será posible ir obteniendo conclusiones definitivas y permanentes.

Es indudable que la elaboración de un plan de ordenación del recurso micológico, así como una regulación del mismo en una determinada zona, debe partir de una serie de asunciones, información, criterios y metodologías sencillas fijadas de antemano que, en caso de no existir, no permitiría afrontar la elaboración fundamentada y coherente de un plan de ordenación y regulación, o bien, sería temporal, económica y materialmente imposible realizarla, de forma escrupulosa y con rigor científico, como parte del propio proceso de ordenación y regulación.

En la presente tesis doctoral se presentan tres trabajos orientados a convertirse en una aportación que sumar al gran objetivo que constituye la gestión del recurso micológico.

Una de las tareas de mayor relevancia tanto en el proceso de ordenación como en el de regulación es la realización de inventarios que pongan de manifiesto la producción de determinadas especies en un ámbito. Como norma general, el hecho de que los planes de ordenación se refieren a amplias zonas con diversas formaciones vegetales, cada una de las cuales albergan diferentes especies de hongos que fructifican en distintas estaciones del año, unido a la necesidad de información actualizada, hace que los muestreos al servicio de la gestión micológica deban ser sencillos, rápidos y valiosos en lo que a información aportada se refiere.

Por ello, el uso de parcelas valladas como unidad principal de inventario periódico en un área ordenada no es el método más adecuado, atendiendo al elevado coste material y económico que supondría. Sin embargo, multitud de autores (Sjöblom *et al.*, 1979; Kalamees & Silver, 1988; Ohenoja, 1989; Fernandez-Toirán, 1994; Martínez-Peña *et al.*, 2011a) han empleado este tipo de parcelas con diferentes objetivos como el estudio de la dinámica de la producción o la diversidad.

Otra unidad muestral ampliamente empleada son los transectos lineales (Wilkins & Patrick, 1939; Parker-Rhodes, 1951; Richardson, 1970; Laiho, 1970; Ohenoja, 1984; Buckland *et al.*, 1993; Lämas & Fries, 1995) que, en base a las diferentes metodologías establecidas por los autores, han servido para estimar la producción micológica.

La metodología de muestreo planteada en este trabajo sienta las bases de un muestreo más sencillo orientado a facilitar la gestión micológica (Martínez-Peña *et al.*, 2011b).

En el proyecto INTERREG IVB SUDOE Micosylva (http://www.micosylva.com), que aborda el estudio de la gestión selvícola de montes productores de hongos silvestres comestibles de interés socioeconómico como fuente de desarrollo rural, se han determinado, como áreas potenciales de muestreo, las parcelas del Tercer Inventario Forestal Nacional por una doble justificación: su localización conocida en las diferentes formaciones vegetales y la amplia información preexistente de variables fisiográficas o dasométricas, entre otras (Martínez-Peña *et al.*, 2011c). Los transectos o recorridos lineales son los elegidos como unidad de muestreo de las citadas áreas.

El muestreo mediante transectos permanentes con reserva de carpóforos aporta dos tipos de información necesaria para facilitar el diseño de la metodología de muestreo buscada. De un lado permite conocer el ancho de banda del muestreo que varía en función de la visibilidad del estrato muestreado y de la propia especie fúngica, en el cual se recolecta el 100% de los carpóforos existentes. Los anchos de banda calculados fueron de 5,3 m y 5,8 m para *Boletus* grupo *edulis* y *Lactarius* grupo *deliciosus*, respectivamente. Estos valores son ligeramente superiores al propuesto por Parker-Rhodes (1951) de cinco metros de ancho de banda como máximo ya que, por encima de este ancho los errores debidos al muestreador son más importantes. El ancho de banda permite conocer el área efectivamente muestreada en la que se asume que se han avistado todos los carpóforos resultando de esta forma la producción en kg/ha.

Por otra parte, este método de muestreo permite calcular la producción que ha sido recolectada, consumida por fauna, malograda o es recolectable. Con esta información es posible establecer relaciones con otros datos más fáciles de adquirir (número de vehículos, recolectores avistados, censo de ganado silvestre y doméstico de la zona, variables climatológicas, etc.) y poder obtener de esta forma la producción bruta de la zona sin necesidad de emplear una metodología tan laboriosa.

Autores como (Hering, 1966; Richardson, 1970; Ohenoja, 1984; Mehus, 1986; Hunt & Trappe, 1987) pusieron de manifiesto la importancia de considerar todos los factores que influyen en la dinámica de producción de hongos ya que, de no ser así, la producción obtenida con determinados métodos de muestreo (excepto unidades con vallado perimetral) resultaría muy alejada de la realidad.

En último lugar, el interés de desglosar la producción reside en la posibilidad de fijar criterios de sostenibilidad. La producción recolectable madura, es decir, la que permanece “disponible” en el monte ostentando la plena capacidad para la dispersión de esporas, puede ser un buen indicador de la presión a la que es sometida una especie, así como de su riesgo a posibles daños irreversibles en su población. Diversos estudios describen cómo en determinadas zonas de Norteamérica y Europa, menos del 10% de los cuerpos fructíferos alcanzan la madurez (de Geus *et al.*, 1992; Martínez-Peña, 2003). En este contexto de recolección abusiva y destructiva, numerosos micólogos han manifestado su temor de que el fuerte descenso en la dispersión esporal provoque cambios en la micocenosis, ya que los nichos ocupados por las especies afectadas podrían ser ocupados por otras competidoras (Arnolds, 1995).

Los hongos micorrícicos dependen nutricionalmente de la planta hospedante, por ello, la actividad fotosintética de esta última condiciona en gran medida el desarrollo y crecimiento de cuerpos fructíferos (Erland & Taylor, 2002; Murat *et al.*, 2008). Así, la planta hospedante contribuirá a la existencia de unas adecuadas condiciones fisiológicas y estado nutricional del micelio, lo que jugará un papel crucial en el desencadenamiento de la fructificación de hongos (Flegg & Wood, 1985).

Son notables los trabajos realizados en la línea de revelar las relaciones existentes entre la producción de carpóforos y los diferentes factores bióticos y abióticos (Martínez de Aragón *et al.*, 2007). En este sentido autores como Bonet *et al.* (2004) han establecido relaciones entre la producción total de hongos y la edad de la masa.

Esta importante dependencia entre ambas especies simbióticas se pone de manifiesto en el momento en que se realiza alguna perturbación en la estructura o condiciones de la masa arbolada que influya en la actividad fisiológica de los individuos que la componen. Por ello, cualquier tratamiento selvícola ejecutado sobre una masa forestal será susceptible de influir en la producción o diversidad de las especies fúngicas, especialmente las micorrícicas. Bajo estas premisas, se acuña el término de “selvicultura fúngica”.

Puede considerarse que una de las actuaciones selvícolas que más influencia tiene sobre la comunidad fúngica son las claras, excepción hecha de la corta final. Las claras persiguen disminuir la densidad de la masa con la finalidad de facilitar el desarrollo de los pies reservados y aumentar de esa forma su valor maderable. Esa liberación de competencia hace que los pies remanentes aumenten su actividad fotosintética con el consiguiente incremento en su crecimiento.

Todos esos cambios pueden ocasionar incrementos en la producción de hongos silvestres (Sjöblom *et al.*, 1979; Kirsi & Oinonem, 1981; Shubin, 1986; Ohenoja, 1988; Egli *et al.*, 1990), aunque es indudable que no afectan por igual a todas las especies fúngicas. Según Egli & Ayer (1997), *Cantharellus cibarius* Fr. parece resultar favorecido por las claras. Los ensayos realizados por el Departamento de Investigación Forestal de Valonsadero, consistentes en el seguimiento a lo largo de tres años de parcelas de *Pinus sylvestris* con diferentes intensidades de claras realizadas por el INIA (Gómez & Montero, 1989), indican que este tratamiento favorecería a algunas especies comestibles (Fernandez-Toirán, 1994).

Pero, como es lógico, no sólo los tratamientos planificados afectan a la producción de hongos. Las propias fases vitales de la planta hospendante determinan cambios en la actividad fotosintética de la misma. El crecimiento de los carpóforos de *B. edulis* y *L. deliciosus* es diferente según la fase en la que se encuentra el árbol. Se ha observado que la tendencia que siguen ambas especies en lo que a tamaño del carpóforo se refiere es similar, presentando los carpóforos con mayores dimensiones en la primera clase de edad. La justificación a este comportamiento se encontraría en los grandes y rápidos crecimientos que tiene el pino en sus primeros estadios que le permiten ser competitivo no sólo frente a otras especies vegetales sino también frente a otros ejemplares de su misma especie, para lograr de esta forma la dominancia que asegure su supervivencia.

Según Montero *et al.* (2008), el máximo crecimiento corriente en volumen para el pino silvestre se sitúa en el Sistema Ibérico entre 40 y 60 años, mientras que el máximo crecimiento corriente en altura se produce, en ésta misma zona, entre los 20 y 40 años y se considera que el crecimiento de la raíz principal se detiene entre los 40 y 50 años (Bravo & Montero, 2008). Teniendo en cuenta todos estos datos podemos concluir que la actividad fotosintética del árbol será mayor en el momento de mayor crecimiento, es decir, al final de la primera clase de edad para el crecimiento en altura y en la segunda para el crecimiento en volumen. Bonet *et al*. (2010) estimó que el área basimétrica es un parámetro muy influyente en la productividad de carpóforos.

Algunos autores encuentran una menor biomasa de carpóforos en masas maduras que en jóvenes (Smith *et al.*, 2002; Dahlberg & Stenlid, 1994; Bonet *et al.*, 2010), aunque en términos de biomasa, no de crecimiento de carpóforos.

De forma independiente al mayor o menor desarrollo de los carpóforos hay que tener en cuenta las condiciones óptimas de fructificación de cada especie que determinarán, en cada caso, los picos de producción.

La influencia de las perturbaciones, bien sean provocadas o por la propia naturaleza de la especie hospedante, en la fructificación de hongos silvestres deben ser tenidas en cuenta a la hora de empreder la gestión del recurso micológico.

La respuesta de cada especie de interés a los tratamientos realizados en su hábitat debe ser estudiada con el fin de programar adecuadamente la selvicultura a aplicar, lo que permitirá optimizar los recursos disponibles, compatibilizando y maximizando su aprovechamiento.

La regulación del recurso también requiere de un amplio conocimiento del comportamiento de la especie. Por ejemplo, el dato de producción de una especie debe ser analizado profundamente ya que no es lo mismo, de cara a la sostenibilidad del recurso, una zona que produzca muchos carpóforos de pequeño tamaño que otra que produzca pocos pero muy grandes. Por ello es importante combinar toda la información disponible sobre producción, biología y ecología de las especies fúngicas de interés para elaborar unos planes de regulación que consigan su objetivo: la conservación y aprovechamiento sostenible del recurso micológico.

Por último, el peso medio por carpóforo expuesto anteriormente tiene una amplia utilidad en la fase de inventario. La metodología de muestreo orientada a la gestión micológica requiere del conocimiento de los pesos medios de la especies muestreadas para el posterior cálculo de las producciones brutas o totales. Por ello, la determinación de pesos medios diferentes para cada clase de edad permitirá ajustar, en mayor medida, las producciones estimadas que si se hiciera con un único valor por especie y formación vegetal.

Se ha destacado en varias ocasiones a lo largo de la presente tesis la importancia económica que está adquiriendo el recurso micológico. Esto hace necesario la elaboración de planes de regulación de la recolección ya que, de otra forma, se terminaría por sobreexplotar las especies fúngicas de interés de manera irreversible, avocándolas a su práctica desaparición. Aunque multitud de autores coinciden en la afirmación anterior, otros sostienen que, al menos a corto plazo, la recolección de carpóforos no afecta a la producción ni a la diversidad fúngica (Jansen & van Dobben, 1987; Egli *et al.*, 2006), aunque el pisoteo y la destrucción consecuencia de una elevada presión recolectora si provocan efectos perniciosos (Egli *et al.*, 2006).

Un proyecto de regulación requiere la planificación y ejecución de una gran cantidad de actuaciones encaminadas a evitar la sobreexplotación o controlar la comercialización, entre otras.

Al haber transformado el recurso micológico en un bien muy codiciado con un valor muy elevado, se hace necesario implantar un sistema de permisos que regule la presión y catidades recolectadas, acompañado, para asegurar el funcionamiento del sistema, de un dispositivo de vigilancia y control (Martínez-Peña *et al.*, 2011c).

Uno de los multiples interrogantes que surgen a la hora de establecer un sistema de permisos es el de establecer el coste de cada uno de los permisos para cada tipología de recolector (comercial, recreativo, foráneo, etc.).

El cálculo del excedente del consumidor permitirá saber en qué margen puede moverse el precio de los permisos sin que coarte la obtención de los mismos por ser demasiado elevado. De Frutos (2010), mediante la aplicación del método de valoración contingente para el cálculo de la disponibilidad a pagar por un permiso de recolección, concluyó en la coincidencia entre la disposición a pagar real e hipotética, es decir, entre la tarifa fijada por el gestor y el precio que los recolectores están dispuestos a pagar.

Los resultados obtenidos en el estudio contenido en la presente tesis, ponen de manifiesto la necesidad de considerar las variaciones interanuales, e incluso intranuales, a la hora de determinar el precio de los permisos ya que, la disponibilidad a pagar es proporcional a las expectativas de recolección. Es decir, en los años más productivos se está dispuesto a pagar más por recolectar setas silvestres.

En resumen, la gestión del recuso micológico requiere de una importante base de conocimiento obtenido a partir de investigaciones centradas en las especies fúngicas y los hábitats de interés. Esta tarea se supone larga y costosa pero, con el tiempo, desembocará en la elaboración de planes de ordenación y regulación cada vez más funcionales y resolutivos.

6 CONCLUSIONES

PROCEDIMIENTO DE MUESTREO PARA LA ESTIMACIÓN DE LA PRODUCCIÓN DE CARPÓFOROS DE HONGOS SILVESTRES COMESTIBLES DE INTERÉS SOCIOECONÓMICO

- La metodología de muestreo diseñada permite desglosar la producción bruta en: producción recolectable (inmadura y madura), producción recolectada, producción consumida por fauna y producción malograda. Para *Boletus edulis* en masas de *Pinus sylvestris* se ha obtenido que, el 24% de la producción resulta recolectada, un 7% la consume el ganado, el 26% se malogra y un 43% corresponde con la producción recolectable, de la cual, un 15% es considerada como madura.

- El ancho de banda calculado, para un muestreo mediante transectos en el cual son detectados la totalidad de los carpóforos, es de 5,3 metros para *B. edulis* y 5,8 m. para *Lactarius deliciosus*, en masas de *P. sylvestris.*

INFLUENCIA DE LA EDAD DE LA MASA EN EL DESARROLLO DE CARPÓFOROS DE HONGOS ECTOMICORRÍCICOS EN BOSQUES DE PINUS SYLVESTRIS

- El peso medio y el tamaño del carpóforo de *B. edulis* es claramente diferente en las tres clases de edad consideradas, presentando el máximo en la primera clase de edad (127 g y 6,8 cm), decreciendo hasta su mínimo en la segunda (68 g y 4,7 cm) y volviendo a crecer hasta un máximo relativo en la tercera clase de edad (79 g y 4,3 cm). De la misma forma, *L. deliciosus* presenta el máximo en la primera clase de edad (48 g y 7,4 cm), decreciendo en la segunda (20 g y 5,8 cm) y también en la tercera clase de edad (21 g y 5,3 cm).

- La tendencia de la tasa de crecimiento de la primera clase de edad es equivalente en ambas especies. Tanto los carpóforos de *B. edulis* como *L. deliciosus* (p-valor<0,05) de la primera clase de edad (< 30 años) presentan un peso mayor que en el resto de clases, reduciéndose éste alrededor de un 50% en la segunda clase.

- La similitud en el comportamiento de ambas especies a pesar de sus diferencias estructurales y ecológicas, permite concluir que es posible que la causa de la similitud resida en la actividad fisiológica del hospedante. El momento de mayor crecimiento de los carpóforos coincide con el de mayor actividad fotosintética del hospedante.

ESTIMACIÓN MEDIANTE EL MÉTODO DEL COSTE DE VIAJE DE LOS BENEFICIOS SOCIALES DE LA RECOLECCIÓN RECREATIVA DE HONGOS SILVESTRES COMESTIBLES

- El excedente del consumidor medio estimado para la recolección recreativa de hongos silvestres en Pinar Grande asciende a 10,49 € por persona y temporada, oscilando entre un mínimo anual en 2005 de 6,05 € y un máximo de 14,91 € en 2001.

- La producción de *B. edulis* influye significativamente (t-valor=2,643) en el modelo del excedente del consumidor, lo que pone de manifiesto la relación directamente proporcional entre la producción o bondad del año y la disponibilidad a pagar por el recolector.

7 RECOMENDACIONES PARA LA GESTIÓN

- Para una gestión micológica eficiente, se recomienda la realización de muestreos más sencillos, basados en transectos con un ancho de banda de 3 metros a cada lado para todas las formaciones vegetales y especies fúngicas muestreadas.

- Las relaciones productivas calculadas permiten fijar los factores de corrección necesarios para estimar, a partir de la producción realmente inventariada, tanto la bruta como el resto de componentes de la misma. A partir de la información obtenida para *B. edulis* en pinares de *P. sylvestris*, se propone emplear, para estimar la producción recolectada, unos coeficientes correctores de 1,5 para presiones recolectoras altas, 0,75 para presiones medias y 0,40 para presiones bajas. Los factores para la estimación de la producción consumida por el ganado son: 1 para presiones ganaderas altas, 0,5 para una presión media y 0,1 para las más reducidas. Estos coeficientes correctores se emplearían para *B. edulis* en cualquier formación vegetal en la que se recolecte.

- El valor obtenido a partir de los muestreos sencillos por transectos planteados anteriormente corresponde con la producción recolectable (madura e inmadura). Se recomienda emplear este componente de la producción bruta como un índice de sostenibilidad. Este índice se basaría en el porcentaje de la producción recolectable madura respecto de la producción bruta. Sería un indicador aceptable del grado de sobreexplotación de una determinada especie. Se recomienda que, de cara a la gestión del recurso, el referido porcentaje no sea inferior al 10% ya que, en caso contrario, la regeneración de la especie y, por ende, su sostenibilidad se podría ver comprometida.

- Dadas las variaciones existentes en la tasa de crecimiento de los carpóforos de *Boletus edulis* y *Lactarius deliciosus* en masas jóvenes respecto de las masas maduras, se recomienda que la frecuencia de muestreo sea también diferente. Se propone que la recolección en masas maduras tenga una periodicidad quincenal dada la menor tasa de crecimiento de los carpóforos, permitiendo así un mayor desarrollo de los mismos. En cambio, en masas jóvenes la frecuencia de recolección podrá ser semanal.

- El excedente del consumidor estimado podrá constituir la base de decisión de los gestores para establecer los precios de los permisos de recolección. Se recomienda, para la unidad de gestión estudiada, una horquilla en el precio de los permisos de 5 a 15 euros para una recolección recreativa de temporada.

SAMPLING PROCEDURE FOR ESTIMATING THE SPOROCARP PRODUCTION OF WILD EDIBLE MUSHROOMS OF SOCIAL AND ECONOMIC INTEREST

Abstract

This study introduces a new approach to determine and assess total mushroom production as well as to partitioning off this gross production into: non-harvested unripe production; non-harvested ripe production; harvested production; production eaten by fauna; and damaged production.

Nine 300 m-long transects were established in the studied area. The sampling method was carried out in 2004, 2005 and 2006. A production of 5.37 kg/ha was estimated for *Boletus edulis* Bull. in 2006 of which 24% of *Boletus edulis* gross production was harvested, 26% was damaged and 15% was recorded as ripe production. The distribution of the gross production by classes permits knowing essential aspects regarding edible mushrooms management including which pressure is undergoing the fungal resource (due to harvesting or grazing), quantity and quality of the production or whether the species regeneration is guaranteed at any moment.

This information allows us to ascertain the fungal resources conservation state and undertake a management and regulatory process for edible mushrooms in the sampled areas.

Key words: Forest management; Mushrooms; Mycological inventory; Sampling; Sporocarp production.

CITATION:

Ortega-Martínez, P., Martínez-Peña, F., 2008. A sampling method for estimating sporocarps production of wild edible mushrooms of social and economic interest. Investigación Agraria: Sistemas y Recursos Forestales 17: 228-237.

1 INTRODUCTION

Mycological resources are often underestimated (Oria de Rueda Salgueiro *et al.*, 1991; Díaz Balteiro *et al.*, 2003), but growing interest in their use has increased the value of edible mushrooms. In the past, harvesting wood had been considered to be the most important resource to be collected from forests in Spain. Today, the revenue from mushroom collection is beginning to approach the return typically expected from timber (Marraco & Rubio, 1992). The harvesting and selling of edible wild mushrooms aid rural development (Boa, 2004) by providing an additional source of income for local inhabitants.

According to a recently published FAO study, 2166 species of wild edible mushrooms are known worldwide and 470 more have medicinal properties. This clearly demonstrates the economic importance of the mushrooms and their relevance as a food source (Boa, 2004).

Edible wild mushrooms are harvested, consumed and marketed in more than 80 countries worldwide, with several million tonnes harvested annually, valued at up to 2 billion dollars (1.35 billion euros) (Boa, 2004).

On the Iberian Peninsula, the amount of commercially harvested *Boletus edulis* species complex has risen to 8,000 tonnes and the amount of *Lactarius deliciosus* to 20,000 tonnes (Oria de Rueda Salgueiro, 1989).

In Castilla y León (Martínez-Peña *et al.*, 2007) the average gross annual production for edible wild mushrooms of social and economic interest was been estimated to be 34,000 tonnes (excluding the *Tuber* genus), produced in an area of 4.5 million hectares. About 54% of the population in Castilla y León picks mushrooms that means a potential of 567,715 local harvesters. Taking into account this potential harvest capacity for the region, up to 65 million euros could be generated as direct incomes for the local harvesters by marketing the main commercial species. Mushrooms also feature on the menus of 55% of restaurants in rural areas of Castilla y León and 54% of accommodations in rural areas have mushrooms harverters among their clients.

These figures clearly show the important role that mushroom harvesting and myco-tourism play in the social and economic development of rural areas in Castilla y León.

The growing value of mycological resources has caused an increase in the amount of mushroom harvesters who often exploit the resources to such an extent that the mycological productivity and diversity becomes endangered (Arnolds, 1991; Boa, 2004). In spite of this, there are some authors who believe the impact of mushroom harvesting on sporocarp production is insignificant (Egli *et al.*, 2006). Faced with this situation of endangerment it is necessary to begin a process leading to the sustainable exploitation of the resource, based on studies aimed at obtaining exhaustive knowledge about the biology, ecology and productivity of edible wild mushrooms of social and economic interest in the region (López *et al.*, 2005).

Quantifying the production of wild mushrooms through mycological inventories is essential in order to identify the communities of fungal macrocmycetes in the sampled area. The production of sporocarps is influenced by a multitude of biotic and abiotic factors that considerably vary though time and space. This lack of uniformity in production makes the desing and the performance of mycological inventories difficult and obligates to adapt the sampling procedure to the conditions of the area, the species sampled and the sampling objectives (Vogt *et al.*, 1992).

All studies about production and diversity of mushroom populations and communities rely on an inventory stage centred on sporocarps (Ohenoja, 1988; Peter *et al.*, 2001; Taylor, 2002; Egli *et al.*, 2006), mycorrhizae (de Roman & de Miguel, 2005), sporocarps and ectomycorrhizae (Clavería, 2007) or mycelium in the soil (Suz *et al.*, 2006; Parladé *et al.*, 2007).

Sampling units used in sporocarp inventories are mainly plots and transects but the sampling method noticeably varies according to the different authors and the peculiarities of their studies.

The objective of this study is to propose a sampling method for estimating mycological production, based on permanent transects of variable width and on marking and monitoring all found sporocarps. Unlike other sampling methods, our methodology allows for the break down of gross production and gives detailed information about the state of the resource.

Other simpler and more economical methods to manage the main edible wild mushroom species of social and economic interest can be develop from the information generated with this sampling method. The aspects that we must take into account are:

1. Harvesting and grazing pressure: when present, pressure from mushroom harvesters and livestock need to be identified and considered in order to better estimate the gross production and assess current state of conservation of the mycological resource.
2. Width of transect: to set the maximum width for all the sporocaps to be detected.

2 MATERIALS AND METHODS

2.1 Description of the study area

The sampling method was used in transects located on the thalwegs of Pinar Grande, a public forest situated in the northern part of the Sistema Ibérico mountain range, in the region of Pinares (Soria). The study area is comprised of 1,749.6 hectares of pure Scots pine (*Pinus sylvestris* L.) stands.

Pinar Grande constitutes a basin of gentle orography, is orientated from west to east and varies in altitude from 1,097-1,543 m. The parent materials of the forestland area comprise siliceous conglomerates, quartzite and sandstone from the Lower Cretaceous period. Soils are brown acid, ferriluvic or ferriargiluvic, with a pH range of 3.8 to 5.6, of a sandy to sandy loam texture with low water retention properties and low soil fertility. Phytoclimatically it belongs to the true nemoro-mediterranean subtype $VI(IV)_2$ (Allué, 1990). Average annual precipitation, according to data from the meteorological station “El Amogable”, is 864.8 l/m^2. Average annual temperature measured at “El Amogable” is 8.8ºC.

According to the 2007 livestock census, Pinar Grande is home to 600 cattle and 700 sheep that graze freely over an area of 6,500 ha. Therefore, the pressure due to livestock in Pinar Grande is therefore 11 cattle unit/km^2. In addition, pressure from game animals amounts to 2.53 roe deer/km^2 and 0.94 wild boar/km^2 while deer is nearly absent (Calvo Vacas & Díez Martínez, 1990).

The pressure from mushroom harvesters varies annually; in 2006 the average daily amount measured over a weekend was nine harvesters/km^2, rising to a maximum of 21 harvesters/km^2, calculated following the methodology of Martínez Peña (2003).

2.2 Sampling

This sampling method is valid for all species of epigeous macromycetes, although in practice and due to the laboriousness of data collection, the sampled species were those of greater social and economic interest in the study area. In the case of Pinar Grande, the sampled species was *Boletus edulis* Bull.. Hypogeous species were not sampled.

Nine permanent transects measuring 330 m in length were established. The distribution of the sample units was carried out using random and stratified sampling (de Vries, 1986). Three transects were placed in each differently aged stand (<30 years; 31-70 years; >71 years) and were sampled weekly throughout the autumn, from September to November, for three years (2004, 2005 and 2006).

Each transect was established with numbered trees, in such a way that from each tree along the transect both the next tree and the previous one were visible. Each transect was defined by the central line, that is, the imaginary line that links the consecutive trees.

The width of each transect varies, amongst other factors, according to the species, the slope or the density of the shrub strata. This width can be calculated from all sporocarps positions after sampling had been carried out. Each colony must be located by measuring the distances between the colony itself and both of the trees (a and b) between which it is situated, taking into account if it is found on the right or the left of the central line of the transect. As the transects are permanent, the distances between every two consecutive trees along the transect (c) were fixed and are measured when the transects were set up. In this way a triangle is formed whose vertices coincide with the sporocarp colony and also the two trees along the transect between which the colony is found.

With these parameters and Heron's formula, which determines the area of a triangle if the three sides are known, the perpendicular distance from the colony to the central transect line (d) can be calculated.

$$p = \frac{a+b+c}{2} \qquad r = \sqrt{\frac{(p-a)*(p-b)*(p-c)}{p}} \qquad d = \frac{2*r*p}{c}$$

The calculation of the width of the transects is based on the detectability of the sampled species. Emlen's method is used to set the detectability coefficients in terrestrial vertebrate census (Tellería, 1986).

The different perpendicular distances calculated for each species are analysed to set a band series of the same width where the detectability diminishes from the first band to the last band. This method assumes that all colonies will be seen in the first band and none will be found any further than the maximum distance of the outermost band.

2.3 Description of the sampling procedure

The main peculiarity of this sampling method consists in the marking, locating and monitoring of the sporocarps seen to know their development over time.

Each transect is sampled by locating all the specimens of the mushrooms species found on either side of the central line, regardless of the distance they are found. Once each sporocarp has been sighted data are collected in the following way:

1. The sporocarp is firstly identified by two numbers, one indicating the colony to which it belongs (the sporocarps separated among themselves less than 1.5 m belong to a same colony) and the other numbering each sporocarp. This identification is used to label a small stake poked in the ground next to the sporocarp.
2. The size of the sporocarp cap is then measured in cm and, if necessary, how ripe it is.
3. The distance is measured from the centre of the colony to each one of the two trees between which the colony has been located. It is also noted if the sporocarp is found to the right or to the left of the central line of the transect.

The recorded sporocarps in the previous sampling should be located to register their evolution, including: the diameter and ripeness if the specimen has continued to develop; recording it as damaged if it has been trampled on, has diminished in size or has been half eaten; or the cause of its disappearance if it cannot be found (harvested or eaten by fauna), as detailed in Table 1.

2.4 Diameter-weight regression and determining ripeness

The sporocarps remain on the study site because they are never collected by the samplers. The weight of each sporocarp is therefore obtained from the cap diameter by using linear regressions. These regressions are obtained from the biometric study of a representative sample of sporocarps of the sampled species, selected at different stages of development in the study area.

Table 1. Signs to explain sporocarp disappearance and to identify the agent involved.

TYPE OF PRODUCTION	SIGNS-OBSERVATIONS
Harvested production	- *Remains of the mushroom left when cleaned by harvesters.* - *Mushroom stalk cleanly cut by a knife.* - *Absence of sporocarp without signs of having been consumed by livestock.*
Production eaten by fauna	- *Ground/top layer disturbed.* - *Remains of an eaten sporocarp.* - *Teethmarks on stalk/cap of the mushroom.*

The average weight of a sporocarp will be calculated with the same sample. The average weight and standard error for *Boletus edulis* is 126±8 g in stands under than 30 years old, 65±3 g in stands understood to be between 31 and 70 years of age and 79±6 g in stands over 71 years old (Ortega-Martínez, 2005).

This sampling method demands a precise division based on the sporocarps ripeness. Ripeness is determined by the spore print. Ripeness can be determined in some species with a change in the colour of the hymenium, while in other species sporulation experiments must be carried out in order to obtain the same outcome. A sporulation experiment is performed using a sample of sporocarps placed with the hymenium facing downwards on a piece of card with a colour that contrast with the spores of the studied species . After a 24 hour period the level of sporulation of each sporocarp can be observed. By relating this parameter with the sporocarp cap diameter a division between ripe and unripe according to the cap diameter is obtained. *Boletus edulis* shows a change in the colour of the hymenium, so white hymenia indicate an unripe state, while greenish-yellow hymenia are characteristic of ripe specimens.

2.5 Calculating production

The gross mycological production (P_B) estimated with this sampling method is divided into a group of addends that separate it into other types of production (Fig. 1):

$$P_{Bi} = p_i + P_i + R_i + G_i + M_i \qquad (1)$$

Where P_{Bi} is the gross production estimated for week i; p_i is the unripe non-harvested production in week i; P_i is the ripe non-harvested production in week i; R_i is the harvested production in week i; G_i is the production eaten by fauna in week i and M_i is the damaged production (trampled, parasitised, uprooted, senescence, etc.) in week i. Each one of these addends can also be subdivided into some groups of components.

The unripe non-harvested production in week i, measured in kg/ha, can be expressed by the following formula:

$$p_i = p_i^i + p_{(i-1)}^{'i} + \left(p_i^{'i} - p_{(i-1)}^{'i}\right) \qquad (2)$$

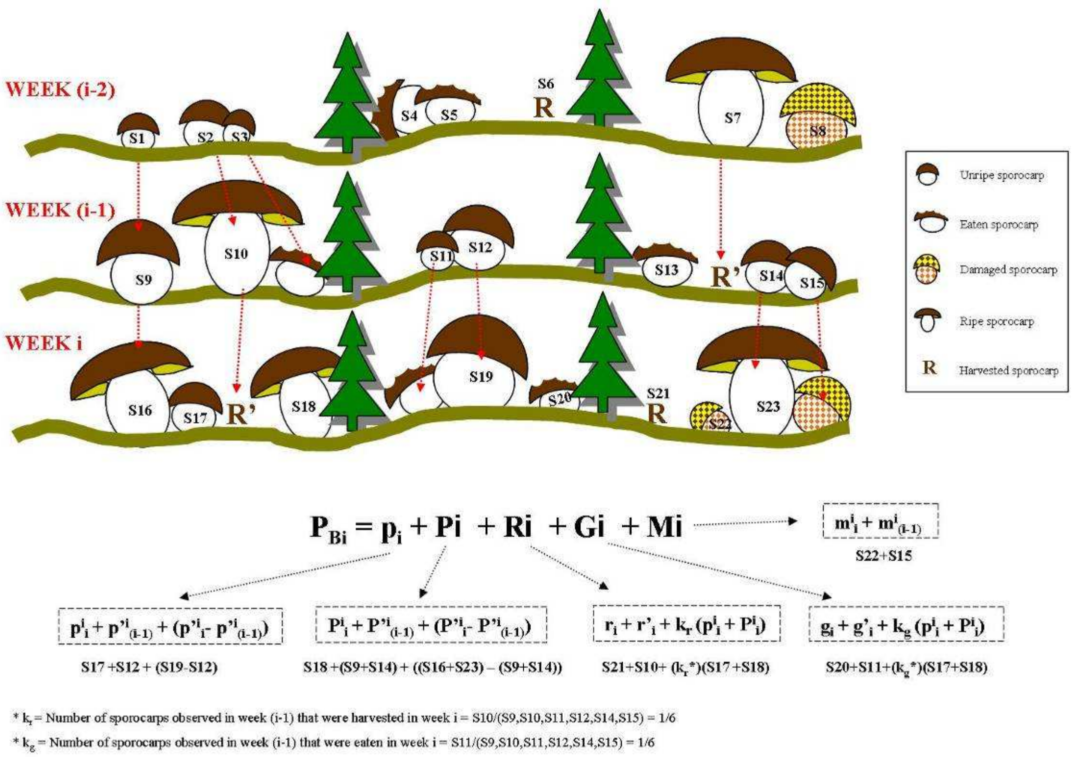


Fig. 1. Descriptive setup of the sampling method and its calculation procedure. In the figure, the sporocarps have been numbered and their weight is considered in the formula.

Where p^i_i is the weight of the new unripe specimens sighted in week i; $p'^i_{(i-1)}$ is the weight in week (i-1) of the sporocarps observed as unripe that week and remained unripe in week i; $(p'^i_i - p'^i_{(i-1)})$ is the difference in weight between week i and week (i-1) of the specimens observed as unripe in week (i-1) and remained unripe in week i, thus obtaining the increase in weight from one week to another.

The ripe non-harvested production (P_i) for week i measured in kg/ha can be calculated as:

$$P_i = P_i^i + P_{(i-1)}^{'i} + \left(P_i^{'i} - P_{(i-1)}^{'i}\right) \qquad (3)$$

where P^i_i is the weight of the new ripe specimens sighted in week i; $P'^i_{(i-1)}$ is the weight in week (i-1) of the sporocarps observed as ripe or unripe that week and remained ripe or ripened during week i; $(P'^i_i - P'^i_{(i-1)})$ is the difference in weight between week i and week (i-1) of the specimens observed as ripe or unripe in week (i-1) and remained ripe or ripened during week i, thus obtaining the increase in weight from one week to another.

Bearing in mind the work of Egli (Egli *et al.*, 2006) it has been accepted that sexual regeneration of *Boletus edulis* is ensured if at least 20% of the gross production remained in situ as P_i.

The harvested production (R_i) for week i is expressed as:

$$R_i = r_i + r_i^{'} + k_r * \left(p_i^i + P_i^i\right) \quad (4)$$

Where r'_i is the weight of the sporocarps observed as harvested in week i and registered the previous week, taking into account the weight they had in week (i-1); r_i are the new specimens observed as harvested in week i, but not previously registered. As these specimens are absent, each one is considered to have the average weight of a sporocarp for each species. It is accepted that there will be a certain amount of specimens harvested in week i that remain undetected due to the lack of any sign of harvesting. To estimate this amount, k_r is calculated, which is the percentage of the number of sporocarps observed in week (i-1) that were harvested in week i. This percentage will be applied to (p^i_i + P^i_i) which represents the non-harvested production of new sporocarps observed in week i (regardless of those observed in previous weeks).

In the same way as harvested production, production eaten by fauna (G_i) can be expressed as:

$$G_i = g_i + g_i^{'} + k_g * \left(p_i^i + P_i^i\right) \quad (5)$$

The equation for damaged production (M_i) is:

$$M_i = m_i^i + m_{(i-1)}^{'i} \quad (6)$$

The addend m^i_i is equivalent to the sporocarps that are observed in week i as damaged (trampled on, parasitised, uprooted, etc) and were not previously registered, assigning them the average weight for each species, as in the previous cases. Likewise, $m'^i_{(i-1)}$ are the specimens that were registered the previous week (i-1) and were found as damaged (dry, trampled or become maggoty) in week i, taking into account the weight of this same specimen the previous week.

In order to obtain the value of the gross autumnal production, the terms corresponding to previous weeks ($p'^i_{(i-1)}$ y $P'^i_{(i-1)}$) as well as the increases that the sporocarps present from one week to another ((p'^i_i - $p'^i_{(i-1)}$) y (P'^i_i - $P'^i_{(i-1)}$)) must be taken away from the gross weekly production to avoid productions accumulations, obtaining the following equation:

$$P_B = \sum P_i^i + \sum p_i^i + \sum \left(r_i + k_r * \left(p_i^i + P_i^i\right)\right) + \sum \left(g_i + k_g \left(p_i^i + P_i^i\right)\right) + \sum m_i^i \quad (7)$$

3 RESULTS

The sampling procedure was used on the *Boletus edulis* species complex only during the autumn (mycological production in autumn is the highest one of the year) of 2004, 2005 and 2006 on nine transects located in Pinar Grande. Only 2006 information has been considered in this section since mycological production in 2004 and 2005 was very poor.

A total of 136 colonies were located with a total of 200 sporocarps of *Boletus edulis* of which 170 were observed in a good state or damaged, the rest were recorded as harvested (22 sporocarps) or eaten by fauna (8 sporocarps).

By analysing the perpendicular distances (PD) of the 136 colonies found it is observed that within a 2 m width either side of the transect all present sporocarps are detected thus the detectability coefficient is 1. Taking the 2 m width, four bands within the belt transect were set up, as it is considered that beyond 8m no individuals are detected (DC=0).

The overall detectability coefficient for *Boletus edulis* for a width of 8m either side of the transect is 0.53 and corresponds to the following function of detectability (see figure 2):

$$CD = (1.04871 - 0.128589 * DP)^2 \qquad (R^2 = 98\%)$$

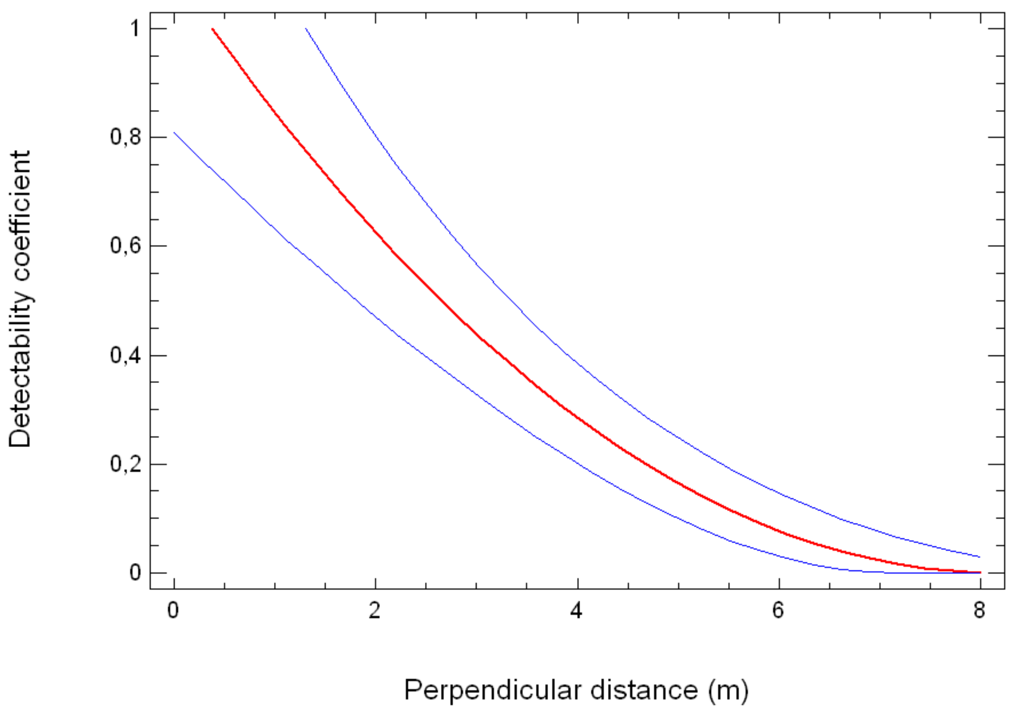


Fig. 2. Function of detectability for *Boletus edulis* in Pinar Grande for a transect width of 8 m. The outermost lines represent the 95% upper and lower confidence limits.

The cap diameter-weight regression employed for the conversion of sporocarps of *Boletus edulis* was (Martínez-Peña, 2003):

$$peso(g) = (1.4477 + 1.19504 * diámetro(cm))^2$$

The average gross production obtained (see equation 1) was 5.37 ± 1.33 kg/ha. This gross production is divided in unripe and ripe non-harvested production, harvested production, eaten and damaged production (see figure 3).

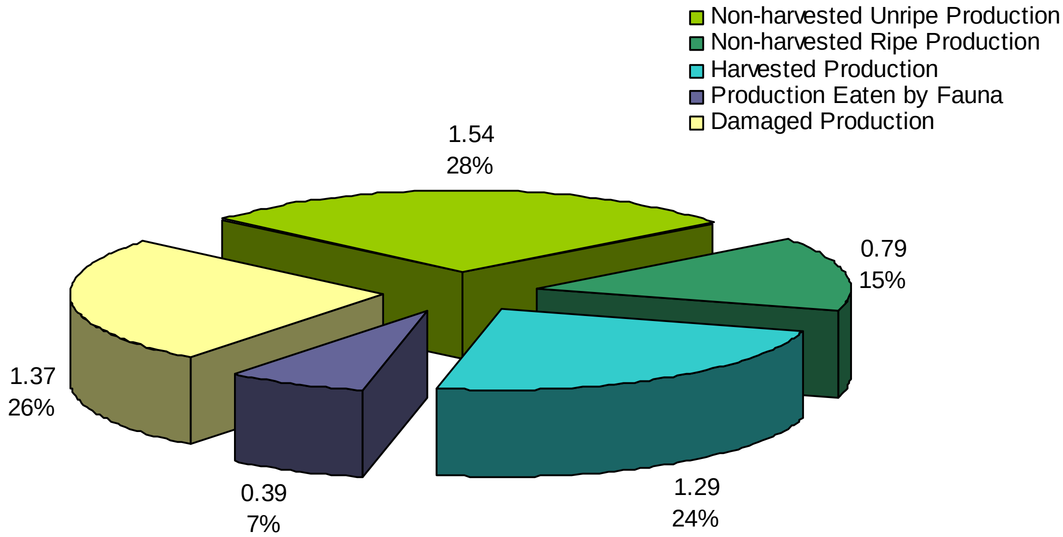


Fig. 3. Percentage distribution of average gross production (kg/ha) of *Boletus edulis* in Pinar Grande.

It has been estimated that 24% of the production of *Boletus edulis* in Pinar Grande is harvested, while 26% of the gross production became damaged. Only 15% of the gross production of *Boletus edulis* was recorded as ripe production capable of sexual regeneration of the species in the forest.

The weekly changes in mushroom production depicted in figure 4 indicate that the weeks during which the production of *Boletus edulis* was higher coincided with those in which the highest number of mushrooms were harvested, showing the largest influx of harvesters occurred when the production was at its highest levels.

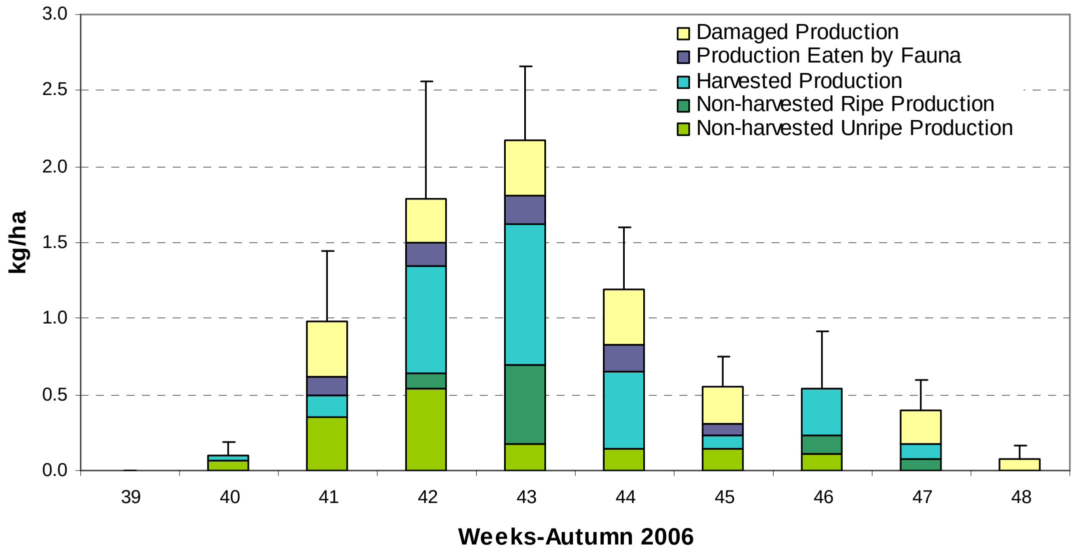


Fig. 4. Distribution of gross weekly production. The *x* axis represents the weeks of the year and the y axis represents gross production in kg/ha.

According to Table 2, only weeks 43, 46 and 47 had high enough non-harvested production to guarantee regeneration (percentages of gross production higher than 20%).

Table 2. Weekly percentage of each type of production in 2006.

Week	Unripe Non-Harvested (%)	Ripe Non-Harvested (%)	Harvested (%)	Eaten by faune (%)	Damaged (%)	Gross production (kg/ha)
39	-	-	-	-	-	0 ± 0
40	69	0	31	0	0	0.09 ± 0.09
41	36	0	14	13	37	0.99 ± 0.46
42	30	6	39	8	16	1.78 ± 0.77
43	8	24	43	9	17	2.17 ± 0.48
44	12	0	43	15	30	1.19 ± 0.41
45	27	0	15	14	45	0.55 ± 0.20
46	19	23	58	0	0	0.54 ± 0.37
47	0	20	24	0	56	0.4 ± 0.20
48	0	0	0	0	100	0.08 ± 0.08

4 DISCUSSION AND CONCLUSIONS

The proposed sampling method allows to estimate the gross production of the study area and to separate it into perfectly defined different types of production.

As well as the considerable temporal and spatial variation inherent to fungal fructification, other factors can lead to a quite substantial underestimation of production if not duly taken into account,. These factors are harvesters and fauna essentially.

Authors such as Richardson (1970), Ohenoja (1984), Ohenoja *et al*. (1984), Mehus (1986) and Hunt *et al*. (1987) highlighted that both agents should be taken into consideration when quantifying mycological production in a forest.

The novelty of this sampling method is that the gross production is separated into its main components. Gross production is easily estimated by using plots and transects with different characteristics (Richardson, 1970; Vogt *et al.*, 1981; Ohenoja & Koistinen, 1984; Mehus, 1986; Ohtonen, 1986; Luoma *et al.*, 2004; Bonet *et al.*, 2004; Kranabetter *et al.*, 2005), although fenced plots are the best way to estimate this production mainly in areas where grazing and harvesting pressures are high (Ortega-Martínez & Martínez-Peña, 2005).

Many authors (Richardson, 1970; Fogel & Trappe, 1978; Luoma *et al.*, 2004) have emphasized the influence of fauna on mycological production, clearly demonstrating that in areas where fauna was present, the sporocarps were either completely eaten or nibbled by animals, which causes errors if it is not taken into account when the mycological production is estimated.

The specimens eaten by fauna were recorded in the inventory for calculating the production of matsutake (*Tricholoma magnivelare*) carried out by Luoma (2006). This author observed any signs of soil disturbance, teeth marks or sporocarp fragments in order to conclude that the specimens had been consumed.

Some studies carried out in the Pacific Northwest United States have tried to reduce the influence of harvesters on the estimations of mycological production in different ways (locating plots in remote areas, posting signs, enforcing no-pick regulations or visiting the plots often) (Pilz & Molina, 2002). This kind of measures is not necessary for the proposed sampling method because the information about harvesting pressure is recorded.

To avoid double counting when it comes to recording the sporocarps and to know conclusively their development over time, a small stake is placed in the ground next to each sporocarp. Nara (2003) used little flag next to the fungi to identify the sporocarps that had been sighted and to avoid double counting. Other authors have marked sporocarps with a innocuous dye on the cap (Egli *et al*., 2006; Luoma *et al.*, 2006).

The weight of each sporocarp is calculated in relation to the cap diameter since the quality of these estimations has been clearly demonstrated in other studies (Liegel *et al.*, 1998; Pilz *et al.*, 1999).

The proposed sampling method takes place on a weekly basis; an interval of this length is considered by Luoma (2006) as optimal to carry out mycological inventories. This periodicity can be adapted to each species if their life cycle is shorter than this interval or they can suffer incessant attacks by insects or other organisms (Richardson, 1970; Mehus, 1986).

The complexity of the data collection is such that it requires skilled labour to be carried out and the duration of the sampling is lengthened considerably (in proportion to the fungal production). This causes an increase of the sampling cost, limits the number of daily repetitions (Fogel, 1981) and can even rule out sampling altogether in particular situations.

The design of any mycological inventory requires the choice of a suitable sampling strategy and sampling effort (Taylor, 2002). This choice will vary, mainly depending on the peculiarities of the area to be sampled (Pilz & Molina, 2002), the proposed objective and the available economic resources. For these reasons, the proposed sampling method will be justified in areas with substantial production of edible wild mushrooms and high harvesting or grazing pressure.

Mycophagous fauna plays an important role in the spores dispersion (Frank *et al.*, 2006) that it can be calculated from the percentage of the gross production that is eaten by animals.

Despite certain authors concluding that harvesting does not affect sporocarp production (Pilz *et al.*, 2003; Arnolds, 1991; Egli *et al.*, 2006), it has been considered that a high percentage of harvested production reveals an excessive exploitation of the resource. It can be assumed that the excessive pressure reduces sporocarp production, if not due to the current harvesting, due to the trampling of harvesters over the area (Egli *et al.*, 2006).

The high percentage of damaged production obtained in the autumn of 2006 in Pinar Grande can partially be explained by the relatively abundant rainfall and mild temperatures recorded during the summer and autumn of 2006, favouring the development of dipterous larvae populations, the principal responsible for the sporocarps to become maggoty (Martínez-Peña, 2003).

The offered results and particularly the breakdown of gross production into percentages show the state of conservation and exploitation of the studied species. The interpretation of the results can be simplified to study the percentage of ripe non-harvested production, given that ripe mushrooms present the greatest potential for sporulation by generating the largest amount of spores produced throughout their life cycle, thus guaranteeing sexual regeneration of the species.

With this information, a based management and regulatory plan can be designed. The criteria obtained using the proposed sampling method (not only for *Boletus edulis* but also for other species), along with other environmental information can represent the basis to establish appropiate management and regulatory conditions (number of permits, species that can be harvested, maximum quantities, space and temporary limits for harvesting, etc.).

TREE AGE INFLUENCES ON DEVELOPMENT OF EDIBLE ECTOMYCORRHIZAL FUNGI SPOROCARPS IN *PINUS SYLVESTRIS* STANDS

Abstract

The study of factors influencing the production and development of wild edible mushroom sporocarps is extremely important in the characterization of the fungi life cycle. The main objective of this work is to determine how tree age influences the speed of sporocarp growth of edible ectomycorrhizal fungi *Boletus edulis* and *Lactarius deliciosus* in a *Pinus sylvestris* stand.

This study is based on information recorded on a weekly basis every autumn between 1995 and 2008 in a set of permanent plots in Spain. Sporocarps are collected weekly and as a result, specimens may not have reached their maximum size. The study area is a monospecific *P. sylvestris* stand. Three age classes were considered: under 30 years, between 31 and 70 years and over 70 years.

Sporocarps of *B. edulis* and *L. deliciosus* grow faster in the first age class stands than in the other two and in the second age class stands sporocarps are more than 50% smaller. The average weight of the picked *B. edulis* sporocarps clearly varies in the three age classes considered, with its maximum in the first age class (127g and 6.8cm cap diameter), minimum in the second age class (68g and 4.7cm cap diameter), and showing a relative maximum in the third (79g and 4.3cm cap diameter).

Lactarius deliciosus sporocarps are on average larger in the first age class (48g and 7.4cm cap diameter), decreasing in the second (20g and 5.8cm cap diameter) and also in the third (21g and 5.3cm cap diameter).

The results show the influence of tree age in speed of sporocarp growth for the two ectomycorrhizal species.

Key words: Boletus edulis, Lactarius deliciosus, stand age class, Scots pine.

CITATION:

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1 INTRODUCTION

Edible mycorrhizal mushrooms are not only a gourmet food but also a source of income for collectors (Wang & Hall, 2004). In Europe, *Boletus edulis* Bull. and *Lactarius deliciosus* Fr. are considered to be two of the most highly valued edible mycorrhizal mushrooms.

Total annual worldwide consumption of *B. edulis* complex reaches between 20,000 and 100,000 tons (Hall *et al.*, 1998). Important markets include North America, France, Italy and Germany (Hall *et al.*, 1998). The estimated annual production of *B. edulis* species complex from the autonomous community of Castilla y León (north Spain) adds up to 8,500 tons, being worth approximately 38 million euros (Martínez-Peña *et al.*, 2007).

Even though it is not as widely appreciated as porcini, *L. deliciosus* has consolidated markets in Europe, Asia and North Africa, where a large amount of those sporocarps are commercialized and comprise a significant source of income (Boa, 2004).

Seedlings mycorrhizated with *L. deliciosus* are available in nurseries throughout the world and the scientific community is making an effort to facilitate the production of seedlings mycorrhizated with *B. edulis* (Ceruti *et al.*, 1987; Duñabeitia *et al.*, 1996; Olivier *et al.*, 1997; Águeda *et al.*, 2008b). Nowadays, both species have to be collected from the wild with variable and unpredictable harvesting from year to year (Cannon & Kirk, 2007; Murat *et al.*, 2008).

However, factors influencing sporocarp formation are not yet apparent. Sporocarp formation is probably the most complicated stage in the life cycle of fungi. This situation is even more complex for ectomycorrhizal fungi, which require symbiotic association with a host plant. Fungal and host genes, environmental and physiological conditions, and nutritional state of mycelium and the host trigger sporocarp formation in ectomycorrhizal fungi, but the process is not fully understood to date (Murat *et al.*, 2008).

Host development entails changes in its physiological state, which influence relations with the host's associated fungal ectomycorrhizal community and, consequently, its fructification.

The aim of this study is to establish a relationship between stand age class and the growth of *B. edulis* and *L. deliciosus* sporocarps.

2 MATERIALS AND METHODS

2.1 Study site

The study site is located in a homogeneous *Pinus sylvestris* L. stand known as "Pinar Grande". It is a 12,533 ha area situated in the Sistema Ibérico mountain range, in the inner north-east zone of the Iberian Peninsula. Altitude varies between 1,097 and 1,543 m.a.s.l. with dominating west and east orientations.

Soils are acidic brown-earths or illuvial, with marked acid pH (4-5), sandy loam to sandy texture, low holding capacity and low fertility.

Medium annual rainfall is 865mm/yr, 69mm/yr falling in July and August and 132mm/yr in September and October. Medium annual temperature is 8.8°C, with July being the warmest month (17.4°C). The frost period begins in November and ends in April, with frequent frosts in late spring and early autumn. Scots pines are felled every 100 years. The forests are silviculturally managed by clear cutting with soil movement and sowing.

In this area, 119 species of epigeous macromycetes fungi have been recorded. They belong to 51 genera and more than half are members of *Russula* Pers., *Cortinarius* (Pers.) Gray, *Tricholoma* (Fr.) Staude, *Amanita* Pers., *Lactarius* Pers., *Collybia* (Fr.) Staude, *Cystoderma* Fayod, *Hebeloma* (Fr.) P. Kumm., *Mycena* (Pers.) Roussel and *Suillus* Gray (Martínez-Peña, 2009).

Boletus edulis and *L. deliciosus* average autumnal sporocarp production in Pinar Grande between 1995 and 2008 by stand age class is detailed in Table 1 (Martínez-Peña, 2009).

Table 1. *Boletus edulis* and *Lactarius deliciosus* autumnal sporocarps mean gross production between 1995 and 2008 in Pinar Grande by stand age class (kg/ha and year) (extracted from Martínez-Peña 2009).

	Age class (years)			Mean
	under 30	31-70	over 71	
Boletus edulis	16,2	84,9	21,9	30,3
Lactarius deliciosus	17,9	3,1	14,9	9,1

2.2 Sampling design

A random sampling design was performed by stand age, according to the forest management plan: 0-15, 16-30, 31-50, 51-70, 71-90, and over 90-years-old. Three plots per age class were installed, providing a total of 18 sampling plots.

Each sampling plot covers a rectangular-shaped area of 150m² (measuring 35x5m). Its size and form were established in line with previous studies by Fernández-Toirán (1994), Kalamees and Silver (1988) and Ohenoja (1989), that use rectangular plots with a minimum area of 100m². Plots were fenced to prevent harvesting and trampling and were at least 500m from stands corresponding to another age class.

For the present study, plots were regrouped by age in three categories: under 30 years, between 31 and 70 years and over 71 years, which represent three clearly different stages in the life of a stand: young, mature and old.

Sampling was performed on a weekly basis from week 35 to week 50 every year from 1995 to 2008, as this period corresponds with most sporocarp emergence. All fully developed sporocarps were collected and identified to species level in the laboratory.

Biometric study focused on two edible ectomycorrhizal fungal species: *B. edulis* and *L. deliciosus*. Speed of sporocarp growth is the analyzed dependant variable. Fresh weight (g) and cap diameter (cm) of each sporocarp collected was recorded for both species. Due to the fact that sporocarps are collected every week, the specimens may have not reached their maximum size.

2.3 Data analyses

Statistical analyses were performed using STATGRAPHICS Plus 5.1 (Statistical Graphics Corp., Warrenton, VA).

The effect of age stand in the speed of sporocarp growth for *B. edulis* and *L. deliciosus* was analyzed by the weight that sporocarps reach in one week using ANOVA. As data proved to be unbalanced, the GLM (General Linear Model) procedure was applied. Tukey´s multiple rank test was used for the multiple mean comparison (Einot & Gabriel, 1975). Data was subjected to a logarithmic transformation for normalization purposes.

Speed of sporocarp growth was also analyzed from the cap diameter that sporocarps reach in one week using the Kruskal-Wallis test for comparing medians due to the fact that normal distribution and homogeneity hypothesis were not reached although logarithmic transformation was performed.

3 RESULTS

Boletus edulis and *L. deliciosus* data analysis show conclusive results on the impact of stand age class in the speed of sporocarp growth. Standard deviation analyses provide valuable information, although the variable weight had been transformed with a logarithm function to comply with the model assumptions.

The average weight of *B. edulis* sporocarps are clearly different for the three stand age classes considered. The maximum is found in the first age class stand, 127g, and decreases for other stands: 68g and 79g, respectively (Table 2 and Figure 1). *Boletus edulis* sporocarps developed under the first age class stand have a larger cap diameter after one week (Table 2).

Table 2. Descriptive statistics for *Boletus edulis* sporocarps weight (g) and cap diameter (cm) reached in one week by *Pinus sylvestris* stand age class (years). Sporocarps were picked every week during autumn between 1995 and 2008.

	B. edulis sporocarps weight (g)						*B. edulis* sporocarps cap diameter (cm)		
	under 30		31-70		over 71		under 30	31-70	over 71
Frequency (number of analyzed sporocarps)	138		721		270		124	675	218
	weight	Log (weight)	weight	Log (weight)	weight	Log (weight)			
Mean	126.8	2.1	68.1	1.8	78.9	1.9	6.8	4.7	5.3
Median	92.5	2.0	40.0	1.6	60.0	1.8	6.0	4.0	5.0
Standard deviation	125.9	2.1	83.5	1.9	65.1	1.8	3.8	2.3	2.5

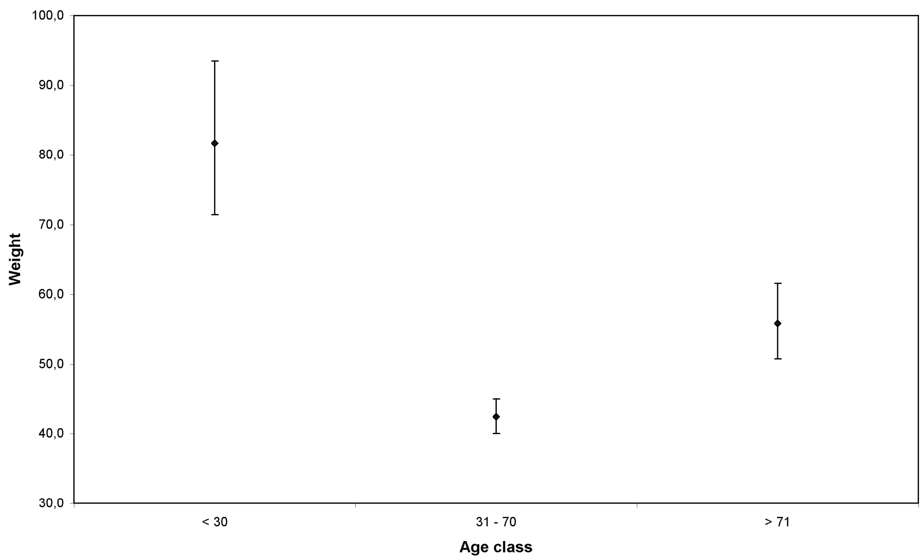

Fig. 1. Means and Tukey intervals (95%) for Boletus edulis medium sporocarp weight reached in one week by stand age class. Pinus sylvestris stand age classes represented in years and B. edulis sporocarp weight in g.

Lactarius deliciosus sporocarps occurring under the first age stand are also of significant weight and are included in the major production stage of the stand (Tables 1 and 3). The maximum is found in the first age class stand, 47g, and decreases for the other two stands: 20g and 21g, respectively (Table 3 and Figure 2). There is not enough data to establish any conclusions regarding cap diameter, but *L. deliciosus* developed under the first stand age class reach larger sizes in one week (Table 3).

Table 3. Descriptive statistics for *Lactarius deliciosus* sporocarp weight (g) and cap diameter (cm) reached in one week by *Pinus sylvestris* stand age class stand (years). Sporocarps were picked every week during autumn between 1995 and 2008.

	***L. deliciosus* sporocarps weight (g)**						***L. deliciosus* sporocarps cap diameter (cm)**		
	under 30		**31-70**		**over 71**		**under 30**	**31-70**	**over 71**
Frequency (number of analyzed sporocarps)	73		36		149		35	6	48
	weight	**Log (weight)**	**weight**	**Log (weight)**	**weight**	**Log (weight)**			
Mean	47.4	1.7	20.3	1.3	21.0	1.3	7.4	5.8	5.3
Median	38.0	1.6	21.5	1.3	17.3	1.2	7.0	6.5	5.0
Standard deviation	35.5	1.6	10.4	1.0	13.1	1.1	2.5	1.6	1.8

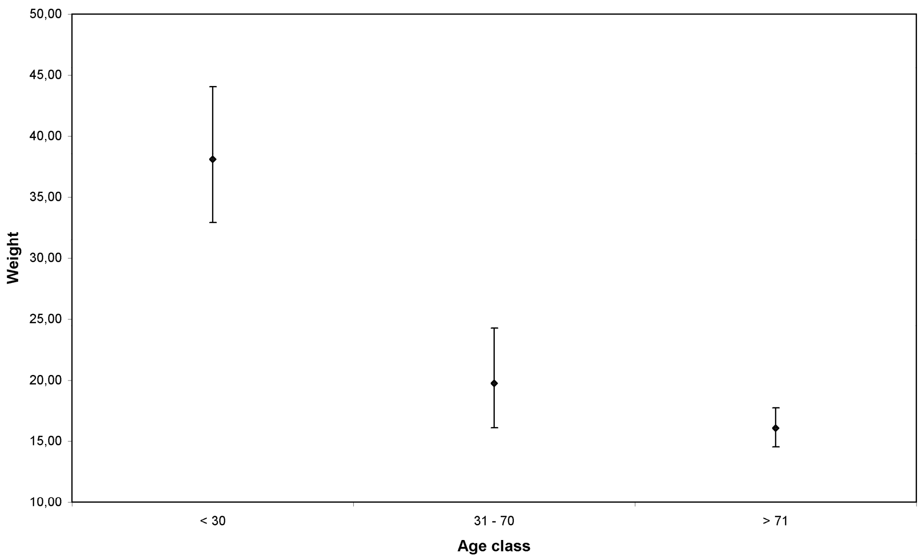

Fig. 2. Means and Tukey intervals (95%) for *Lactarius deliciosus* medium sporocarp weight reached in one week by stand age class. *Pinus sylvestris* stand age classes represented in years and *L. deliciosus* sporocarp weight in g.

Boletus edulis and *L. deliciosus* developed under the first age class stand are heavier than those growing in the two other studied categories. The weight of sporocarps in the second age class is nearly 50% lower than in the first.

4 DISCUSSION

The variable under evaluation is sporocarp growth in one week, as sporocarps are picked every week and not at the end of their development. Both species grow faster when they are associated with pine trees in the first age class.

Boletus edulis and *L. deliciosus* sporocarps occurring in the first age class are larger than in the rest of the classes and nearly 50% heavier in the first than in the second.

This similar behavior is surprising, considering the great differences between these two species. Firstly, *B. edulis* sporocarps are usually collected in old stands (Dighton & Mason, 1985), as they are representative of late succession stages in the ectomycorrhizal fungal community. Conversely, *L. deliciosus* sporocarps are usually collected in young stands, being a typical member of early succession stages. In *Pinus pinaster* Ait. stands, *L. deliciosus* reaches its maximum production in the first and in the last age classes (Fernandez-Toirán *et al.*, 2006; Ágreda & Fernandez-Toirán, 2008).

Another main difference between the two species is in their microscopic structures. *Boletus edulis* is a long distance species (Agerer, 2001), with highly differenced rhizomorphs, formed by hydrophobic hyphae (Águeda *et al.*, 2008a). These features make *B. edulis* highly efficient in transporting water and nutrients to the host and very resistant to ecologic adversities due to its ability to absorb water from deep soil horizons (Lilleskov *et al.*, 2009). *L. Deliciosus,* however, is a medium distance subtype smooth species (Agerer, 2001), with rhizomorphs formed by undifferentiated hyphae (Uhl, 1988). Furthermore, the manner in which a determined species extends in the soil and the differentiation of their extramatrical mycelium and rhizomorphs in ectomycorrhizal fungi is an extremely important ecological factor for tree performance (Agerer, 2001).

Extramatrical mycelium and rhizomorphs are structures specialized in water and nutrients collection and transport to the host. Mycorrhizal fungi not only cover the portion of the root where absorption of nutrients predominates, but create an extensive and dynamic mycelial network ranging far from the root tip and even into the bedrock (Allen, 2009; Lilleskov *et al.*, 2009).

Sporocarp formation is probably the most complex phase in the life cycle of a fungus. It involves dramatic changes of the growth pattern: from a loose mesh of undifferentiated hyphae a compact multihyphal structure is formed and devoted to sexual reproduction (Murat *et al.*, 2008). The situation is even more complex for ectomycorrhizal fungi, as the sporocarp represents a unique step in a complex life cycle, which requires the symbiotic association with a plant host (Murat *et al.*, 2008).

Abiotic factors, such as light, temperature, humidity and nutrient availability, exert a decisive influence on sporocarp formation (Erland & Taylor, 2002; Murat *et al.*, 2008). These factors could be considered homogeneous in this study. In general, sporocarp development in the ectomycorrhizal fungi is induced by temperature drop, high humidity, neutral or slightly acidic soil and solar light, although universal conditions triggering development are still unknown.

Nutrient availability is a factor of major importance in sporocarp formation. Although the composition of the ectomycorrhizal fungal community on the roots is more or less constant throughout the seasons, hyphae abundance is more dynamic and variable (Koide *et al.*, 2007). Moreover, hyphae abundance of soil mycelia are of vital importance, although there is not always a direct relationship between mycelial volume and sporocarp production (Gardes & Bruns, 1996) as it depends on biotic, abiotic and physiological factors to a large extent (Smith *et al.*, 2002; Erland & Taylor, 2002). In fact, it has been demonstrated that the production of *Tuber melanosporum* Vittad. sporocarps are related to the decrease of extrarradical mycelium in the soil (Suz *et al.*, 2008).

Physiological conditions of the host are crucially important factors that trigger sporocarp formation in ectomycorrhizal fungi (Flegg & Wood, 1985).

Scots pine in the *Sistema Ibérico* mountain range has its maximum current annual increment in volume when it is 40-60-years-old while maximum current annual increment in height takes place when it is 20-40-years-old (Montero *et al.*, 2008). Main root growth stops between 40 and 50-years-old (Bravo & Montero, 2008). Scots pine in Spain has its maximum relative increment for basal area and volume when it is approximately 10-years-old, 11%, decreasing considerably from 20-years-old onwards (Montero *et al.*, 2008). Considering these facts, it could be reasoned that host photosynthetic activity is higher when its growth is at its maximum, namely at the end of the first age class for height and basal area increment and the second age class for volume increment.

Trees require more nutrients in their early development phases when growth rates are faster. The fungus could be using these circumstances to its own advantage as it is not capable of surviving without a host and can use more nutrients, complex or otherwise, in the development of its sporocarps.

Some authors found less sporocarp biomass in old-growth stands than in younger stands (Smith *et al.*, 2002; Dahlberg & Stenlid, 1994; Bonet *et al.*, 2010). Although those studies analyzed sporocarp biomass, not speed of growth, their results could be explained in a similar way to those presented here.

Bonet et al. (2010) revealed that stand basal area is a strong predictor of sporocarp productivity. The basal area associated with maximum sporocarp productivity coincides with the peak of annual basal area increment in the studied pine stand, when the pine-trees are 20-40-years-old, suggesting that resources needed for tree growth and for sporocarp production come from a common pool.

Similar positive relationships between the photosynthetic rate of the host and speed of sporocarp growth could explain the facts presented here. In the present study, *L. deliciosus* shows a higher speed of sporocarp growth in young stands, when biomass production is at its highest (Table 1). *Boletus edulis* has a higher speed of sporocarp growth in young stands, while its greatest biomass production is not in young stands (Table 1), because the species is not representative of early succession stages.

A clear mechanistic hypothesis as to why the speed of sporocarp growth might vary according to tree age class cannot be provided. Further investigation is necessary to obtain these results. The study of the sporocarp behavior has allowed us to increase our knowledge of the ectomycorrhizal fungi life cycle and its spatial and temporal variability, providing suitable information to subsequently develop appropriate management tools for this valuable natural resource.

ESTIMATING THE SOCIAL BENEFITS OF RECREATIONAL HARVESTING OF EDIBLE WILD MUSHROOMS USING TRAVEL COST METHODS

Abstract

The public demand for recreational harvesting of edible wild mushrooms has risen over the last two decades and currently affects all forestry areas with mycological resources in Spain. The idea of introducing a system of 'user-pays' fees has been conceived as a possible ecosystem management strategy. Valuing the recreational benefits people derive from harvesting edible wild mushrooms may provide some guidance as to how much people would be willing to pay and may also justify future taxes for on harvesters. Environmental valuation methods allow the benefits of this recreation activity to be estimated. In this case, the authors estimate a demand model of recreational harvesting of edible wild mushrooms in '*Pinar Grande'* (Soria, Spain) through the zonal travel cost model, its consumer surplus associated and explanations factors.

Key words: Recreational harvesting of edible wild mushrooms, zonal models, estimated consumer surplus.

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1 INTRODUCTION

The public demand for recreational harvesting of edible wild mushrooms has risen over the last two decades and currently affects all forestry areas with mycological resources in Spain, impacting on private and public forest landowners. Despite its growing social and economic importance as a forestry resource (Díaz Balteiro *et al.*, 2003; Martínez-Peña, 2003), the harvesting of wild mushrooms continues to be overlooked in forestry management.

Various authors have investigated into the management of mycological resources (Hosford *et al.*, 1997; Fernandez-Toirán, 1994; Palm & Chapela, 1997; Martínez-Peña, 2003). The idea of introducing a system of 'user-pays' fees, therefore, has been conceived as a possible solution. Since 2003, edible wild mushroom harvesting has been regulated in the forests of the Castilla y León region. In 2006, 60,630 hectares were regulated using the methodology explained below. The regulation of mushroom harvesting is carried out by signposting the areas of harvesting with notices stating where to collect or not, vigilance of harvesters, commercial control and harvester licences ('user-pays' fees).

In forests which are regulated, it is therefore necessary to hold a mushroom harvest licence. This licence could be valid for a day or a year and with two different kinds of licence to choose from according the harvest activity: a recreational harvest licence (for quantities of mushrooms harvested below 3 kg) or a commercial harvest licence (unlimited quantities).

The price for a recreational and daily harvest licence is 5 €. Whereas, the price for a recreational and annual harvest licence is variable, according to the region where the harvester has come from. However these recreational licence prices are not related to the demand generated by harvesters, due to the fact that these functions have not been estimated through environmental valuation methods. These techniques allow the benefits of this recreation activity to be used as guidance for policy makers. Valuing the recreational benefits derived from the harvesting of edible wild mushrooms may provide some guidance as to how much harvesters would be willing to pay and may justify future taxes.

Therefore, the object of this paper is to provide a recreational demand analysis of non-commercial mushroom harvesting in the '*Pinar Grande*', using travel cost methods.

A wide selection of empirical literature is available on outdoor recreation demand (Brouwer & Spaninks, 1999; Rosemberg & Loomis, 2001; Morrison *et al.*, 2002; Amjath Babu & Suryaprakash, 2008). Much has also been written about "non-timber values" (Balkan & Kahn, 1988; Layman *et al.*, 1996; Knoche & Lupi, 2007) focusing mainly on the recreational aspects of hunting and fishing. Unfortunately this literature lacks estimates of edible wild mushroom harvesting (Starbuck *et al.*, 2004). Spain also has a wide array of literature on forest recreation aspects (Riera, 1997; Riera, 2000; Garcia & Colina, 2004; Mogas *et al.*, 2005), but few studies focusing on "non-timber values" (Martínez-Peña, 2003; Martínez de Aragón, 2005).

2 MATERIALS AND METHODS

2.1 Description of study area

The study area is located in a public forest known as '*Pinar Grande*', which covers an area of 12,533 hectares. This forest is situated in the northern part of Sistema Iberico mountain range, in the region of "Pinares" (Soria). The study area is comprised of pure Scots pine (*Pinus sylvestris* L.) stands and small stands mixed with *Pinus pinaster* Ait., *Quercus pyrenaica* Wild. or *Fagus sylvatica* L. The most representative genera for biomass of epigeus macromycetes are: *Russula* (25.8 %), *Suillus* (21.1 %), *Boletus* (15.8 %), *Amanita* (8.5 %), *Pholiota* (5.8 %), *Cortinarius* (5.6 %) y *Tricholoma* (3.8 %) (Fernandez-Toirán & Martínez-Peña, 1999). The most harvested species are *Boletus* gr. *Edulis* and *Lactarius* gr. *deliciosus* (García-Cid, 2002).

'*Pinar Grande*' has been managed since 1907, although nowadays it is mainly exploited for timber. Even though timber cutting and cattle can modify mushroom production, these do not disturb mushroom harvesting. However, mushroom harvesting is prohibited during the hunting season. Mushroom harvesting is not considered with sufficient detail in Pinar Grande management plans, despite its social and economic importance. In fact, mushroom harvesting could represent 6% of the value of timber, which collects income of €9 per hectare, even without taking into account the recreational value generated by mushroom harvesting (Martínez-Peña, 2003). Other management alternatives show that the net present value generated by mushroom harvesting could be 40 % of the value obtained by timber cutting (Aldea, 2009).

Currently, the landowner of "Pinar Grande" does not obtain any income from mushroom harvesting and neither is it included in the regulated areas with harvesting licences, however this may change in future.

2.2 Methods

The travel cost model (TCM) of estimating the demand function has been applied to a wide range of recreational activities including hunting, fishing and forest recreation (Ward & Bell, 2000). The TCMis the approach selected to estimate the consumer surplus associated to recreational harvesting of edible wild mushrooms in '*Pinar Grande'*. Firstly, it is one of the most popular valuation techniques in measuring the value of a non-market resource (Inhyuck, 2007). Secondly, its application is cheaper than other methods, in particular contingent valuation methods and this reason is particularly important in situations such as this one which do not have financial backing.

This method has been developed from a suggestion made by Hotelling (1947) in a publication on the economist recreation in US national parks by the National Park Service. Hotelling suggested using the travel cost incurred by an individual when visiting a recreation site as an implicit price for the services of that site. Exploiting the empirical relationship between increased travel distances and associated declining visitation rates would permit one to estimate the demand relationship. In this way, the Marshallian demand curve for the recreation service can be estimated and appropriate consumer surplus measures calculated and thus provide a basis for comparing them with the cost of their supply.

Two major variants of the TCM are the zonal travel cost method (ZTCM) and the individual travel cost method (ITCM). A general reduced-form demand function relates visitation rates (VI) to travel cost (TC) and other relevant variables (X_i) and can be specified as:

$$VI_i = \alpha + \beta_1 TC_i + \beta_2 X_{2i} + \beta_3 X_{3i} + \Lambda + \varepsilon_i \qquad [1]$$

Where α is the intercept, the β's are the regression parameters and ε_i is the error term indicating each zone or individual .

In the ZTCM, the area surrounding the recreation site is divided into various zones. Each zone has an average travel cost according to its distance from the site (Garrod & Willig, 1991). The visitation rate per zone, in a given time period, can be estimated using the average travel cost. Several authors have applied this version to estimate the demand relationship (English & Bowker, 1996; Bateman *et al.*, 1999; Bennear, 2005; Inhyuck, 2007). Various Spanish authors have also written on this subject (Campos & Riera, 1996; Martínez-Peña, 2003; Riera & Farreras, 2004).

However, this approach has two important limitations (Ward & Bell, 2000). Firstly, there is the difficulty in accounting for the effects of travel time on individuals, since there is a high correlation between travel cost and travel time when individual experiences are averaged to estimate zonal values. In order to overcome multicollinearity in the regression analysis, travel time must be omitted. Secondly, the aggregation and averaging process required to estimate zonal values make certain demand determinants, particularly the socioeconomic variables, statistically non-significant. In effect, there is a loss of information efficiency.

The ITCM on the other hand, uses survey data from individual visitors to link the demand of natural resources to its determinants. These include how far the visitor must travel to get to the site, the amount of time spent travelling, travel and on-site expenses, their income and other socioeconomic characteristics, etc. Therefore, this method allows the amount of visits purchased at different prices to be calculated. The two advantages to the ITCM are that it follows conventional methods used by economists to estimate economics values based on market prices and also relies on what people actually do rather on what people say they would do in hypothetical situations (Bell & Leeworthy, 1990). Due to these reasons and to the weak theoretical foundation of the behavioural patterns in the aggregate demand models, this version is preferred over the ZTCM (Bhat *et al.*, 1998; Pérez y Pérez *et al.*, 1998; Riera, 2000; Buchli *et al.*, 2003; Garcia & Colina, 2004; Nillesen *et al.*, 2005), but in any case, economic theory shows individual models to be superior to zonal models (Fletcher *et al.*, 1990).

In this sense, empirical studies provide mixed results. For example, the ZTCM is considered more appropriate to estimate consumer surplus when visits are uniformly distributed and ITCM is more suitable for the case for multiple-destination due to the difficulty of obtaining the site-specific travel cost estimates (Cook, 2000). Given the availability of data and simplicity of application, the zonal approach has been used in this study. This methodology uses relatively straightforward demand models that, given certain research objectives, can indeed perform as well as individuals models (Hellerstein, 1995). We believe that this approach is suitable because the visits are uniformly distributed among Spanish provinces and recreational harvesting is the only reason to visit Pinar Grande in the autumn season (see data).

However, there are a number of problems that may arise in the implementation of the TCM. Two of them are briefly discussed here. The first is the choice of functional form used in the estimation of the demand curve. The economic theory of constrained optimisation with weak complementarity does not imply any particular functional form for the trip generating equation. Given no *a priori* guidance, the functional form is decided according to which fits the data better. This decision has important implications for the results obtained and affects both the expected value and variance of consumer surplus estimates (Ziemer *et al.*, 1980; Adamowizc *et al.*, 1989; Hanley, 1989; Hellerstein, 1991; Ozuna *et al.*, 2003).

Three functional forms were used to estimate the econometric model of visitor demand; linear, semilog, and exponential specification functions. Linear models are the most commonly used to estimate using ordinary least square (OLS) regression. None of the variables need to be transformed, thus minimising potential coding errors. They are also easy to interpret for policy makers investigating visitor rates. However, linear models have been less popular during the last 20 years of published research in TCMs because the goodness of fit is worse than nonlinear forms (Ward & Bell, 2000). This is particularly the case where there are few visits at very high prices and many visits at near-zero prices. In our case, linear function had the least adjusted R^2 compared to the other two models so we rejected this approximation. Semi-log models, where the dependent variable is transformed by taking the natural logarithm, are commonly used in literature such as Ziemer *et al*. (1980), Vaughan *et al*. (1982), Strong (1983) or Willis and Garrod (1991). This specification shows the best adjusted R^2, however, the test for the present of heteroscedasticity rejects the null hypotheses of homocedasticity, which would bias the estimates of parameters variance and lead to incorrect statistical conclusions, and therefore, we also rejected this specification. The third specification presents the second best adjusted R^2 after the semi logarithmic model and thus the exponential specification for the Clawson and Knetsch model was selected.

The second widely discussed aspect of TCM is the specification of the monetary price of recreation trip. There are four kinds of travel cost that could be used in a TCM study: petrol cost; full car running cost; out-ofpocket cost; and travel time cost, as well as the added decision for the investigator in determining which the part of the total travel cost to consider when a person or a family visits several sites during the trip.

In order to minimize the effect of the monetary travel cost specification on the estimated welfare measures only petrol cost is taken as an approximation of the travel cost. Although not common practice, it is a more cautious measure. If the obtained measures are to be used as a guide in making forest policy decisions, these values would need to be the most cautious possible and cannot be seen to be influenced by the decisions taken by the investigator (Randall, 1994).

The following demand function was estimated for all years between 1997 and 2005 as follows:

$$Ln(VI_i) = \alpha + \beta_1 * {}^{1}\!/_{TC_i} + \beta_2 * GDPpc_i + \beta_3 * MS_i + \varepsilon_i \qquad [2]$$

Where i-zones are Spanish provinces, equivalent to two digits statistical division of National Statistics Institute (Spanish Statistical Office). VI_i are the visitation rates of area i, defined as visitation per 1,000 inhabitants and were calculated using the following formula:

$$VI_i = \frac{V_i * 1000}{P_i} \qquad [3]$$

TC_i are the vehicular travel costs based on average running petrol costs per kilometre between the capital of area i and the study site. It is expected that this variable would be negative, in the sense showed by the economic theory. $GDPpc_i$ are the per capital gross domestic product of the i areas, used to display the effect of level income on the demand function. Therefore, the expected sign of this variable would be positive in the sense shown by the economic theory. MS_i are the number of mycological societies in the i areas and could be used to show the preferences of the inhabitants of these areas in the recreational harvesting of edible wild mushrooms. The expected sign of this variable would be positive in the sense shown by the economic theory.

The initial models included the migration rates of I zones (MR_i), defined as the percentage of persons of i areas who were born in Soria. This variable could shows the importance of these people born in Soria who return to the study area every year in picking season as they did when they lived in Soria. However, this variable is correlated with the distance and, therefore, with the cost of the trip, generating multicollinearity problems. Therefore, this variable was eliminated from the demand equation. The explanatory reasons for this behaviour are that the population emigrates to nearest provinces.

The estimated travel costs regression coefficients can be used to determine the value of recreational harvesting of edible wild mushrooms in '*Pinar Grande*' in terms of consumer surplus in any year. Using an evaluation technique, often known as the Hotelling-Clawson approach, the travel cost coefficient is used as a measure of sensitivity of participants to added cost, such as a harvest fee (Clawson & Knestch, 1966). If *hf* is the added cost, equation [2] becomes:

$$\frac{\hat{V}_i * 1000}{P_i} = e^{\hat{\alpha} + \frac{\hat{\beta}_1}{(TC+hf)_i} + \varepsilon_i} \qquad [4]$$

Where $\hat{V}_i$ is the estimated numbers of annual trips from area *i* to *Pinar Grande* and $\hat{\alpha}$ and $\hat{\beta}_1$ the estimated regression parameters. We can refer to the relationship in equation [4] as the Marshallian or *uncompensated* demand curve which includes the income effect of a price change. Integrating this equation for each year, results in an estimate of the annual Marshallian consumer surplus (MCS) in the absence of a harvest fee[1]. The maximum willingness to pay every year for the area under the travel cost derived demand curve (Anex, 1995) is calculated. This estimation could be an accurate approximation of the individual recreational harvester's welfare under the assumption of a free access situation. Equation [4] can be integrated as follows:

$$MCS = \int_{atc}^{mtc} e^{\hat{\alpha}+\frac{\hat{\beta}_1}{TC}} dTC \qquad [5]$$

Where *atc* is the weighted average actual travel cost in every year and *mtc* is the cost at which no trips are demanded, also known as the chock price. Given the characteristics of the estimated demand function, the chock price would be infinite. The calculation of the Marshallian consumer surplus would not be possible using an infinite price chock. In order to solve this problem travel cost was replaced by the maximum cost possible to access the zone from within Spain. This decision has been justified by it being improbable that trips are demanded from a greater distance.

The mathematical solution of the integration process returns the following formula (see appendix) to calculate the MCS of recreational harvesting of edible wild mushrooms in '*Pinar Grande'*:

$$MCS = e^{\hat{\alpha}} \left\{ (mtc - atc) + \hat{\beta}_1 \ln \frac{mtc}{atc} + \sum_{n=0}^{\infty} \left[\frac{\hat{\beta}_1^{\,n+2}}{(n+2)! * (n+1)} * \left(\frac{1}{atc^{n+1}} - \frac{1}{mtc^{n+1}} \right) \right] \right\} \qquad [6]$$

Finally, we tested the explanation factors of the Marshallian consumer surplus in every year adjusting the following equation using OLS regression:

$$Ln(MCS_t) = \alpha' + \beta'_1 * BEFP_t + \beta'_2 * BEFP_{t-1} + \beta'_3 * CP_t + \varepsilon_i \qquad [7]$$

Where t are the years between 1997 and 2005. MCSt are the estimated Marshallian consumer surplus in every year, and $BEFP_t$ are the fit production in kilogrammes per hectare of the most important species harvested in *'Pinar Grande'*

[1] The hicksian compensating variation and equivalent variation welfare measures are the theoretically correct measures of the value of the benefits, even though Willig (1976) showed that consumer surplus is an acceptable approximation.

(*Boletus edulis*) in every year. The expected sign of this variable would be positive, in the sense of bigger harvests: greater satisfaction. $BEFP_{t-1}$ are the retarded fit production in kilogrammes per hectare of the most important species harvested in *'Pinar Grande'* (*Boletus edulis*) in every year. The expected sign of this variable would be positive because harvesters could travel to the study area expecting find it in the same condition as the previous year. CP_t are the cost of petrol in every year. The expected sign of this variable is indeterminate and depend on demand elasticity- price of equation 2. If petrol cost was to change, it could impact on the number of visits, the sign would be negative and vice versa.

The initial model included the number of mycological societies in Spain in every year (MS_t). However, this variable was correlated with the cost of petrol (CP_t), generating multicollinearity problems[2]. This variable was eliminated of the analysis.

2.3 Data

Aggregation (i areas) was selected on a provincial level for two reasons. Firstly, the sample plates only were available in this disaggregation level and, therefore, it was the only way to get the dependent variable V_i. Secondly, in Spain there is no reliable statistical information to lower aggregations, except on a municipal level, but disaggregation occurs to such an extent that it does not respond to the focus of the study. Higher aggregation was possible at one digit statistical division of National Statistics Institute (Spanish Statistical Office) equivalent to Autonomous Communities level, but this aggregation was rejected due to the loss of information efficiency. Spain has 52 provinces, the autonomous cities of Ceuta and Melilla included. Five of them were eliminated because is not possible travel to the study site by car.

The total visitation of recreational harvesting of edible wild mushrooms per zone data (V_i) were collected by the Department of Forestry Investigation, Valonsadero (a department dependent on the regional government), in the study area from 1997 to 2005. This data was obtained from weekly surveys on forest tracks accessible to vehicles randomly selected in the '*Pinar Grande'* forest. The surveys counted the number of parked vehicles belonging to harvesters and their province of origin according to the number plates. The sampling was always performed following the same pattern, starting and finishing at the same time of day, covering the 16 forest tracks (29.5km of

[2] These variables have a growing trend during the study period.

the total 96.5km of forest tracks accessible in the forest). The sampling was carried out on a weekly basis throughout the autumn every year from 1997 through to 2005, totalling 126 samples. Each sample allowed for an estimation of the average number of harvesters per kilometre of forest path per day from each province of origin. Multiplying this figure by the total 96.5km (of forest tracks), the total number of harvesters per day who had travelled from each different place was calculated for the whole of '*Pinar Grande'* (Ortega-Martínez, 2005).

Although the mushroom harvesting takes place in spring and autumn, only autumn was considered for the inventory of production and vehicles as this season is the most important in terms of production and harvester activity. In any case, the sample was considered sufficiently representative because it takes into account 30 % of the total forest tracks in the areas with poor accessibility and lower quality of mushroom production. Moreover, when the number plates of the vehicles were insufficient to ascertain the origin of vehicle, the distinguishing dealership sticker was used.

All of the vehicles belonged to mushroom harvesters, because according to vehicle surveys for this area during the year, vehicles are only observed when harvesting of edible wild mushroom occurs in autumn.

Commercial harvesters were eliminated from the analysis of annual samples using data from the Department of Forestry Investigation,Valonsadero. The percentage of commercial harvesters was extracted from the total number of harvesters in terms of their province of origin.

The vehicular travel costs (TC_i) were calculated for a range of different types of cars under the assumption that the type of vehicle a person owns and the price of the petrol does not depend on the zone of origin and that costs per kilometre are the same across all zones. For each year, the weighted-average running cost in current euros was calculated using data from the Minister of Industry, Tourism and Trade on distances and prices of petrol (MITT (Minister of Industry Tourism and Trade), 2005).

The population per zone i (P_i) and per capita domestic gross product of i zones ($GDPpc_i$) were collected of the National Statistics Institute (NSI (National Statistics Institute), 2005).

The number of mycological societies in i zones (MS_i) were collected from several sources like mycological publications, association web sites, regional governments requests, etc.

Finally, the fit productions in kilogrammes per hectare of the most important species harvested in 'Pinar Grande' (*Boletus edulis*), $BEFP_t$ and $BEFP_{t-1}$, were collected in the study area during the period 1997-2005 (Martínez-Peña, 2009).

3 RESULTS

The results of the ordinary least squares estimation of the demand models described by equation [2] for all years are presented in Table 1 and 2.

Table 1. Ordinary least squares estimates for recreational harvesting of edible wild mushrooms in 'Pinar Grande' (Soria-Spain): summary models and Marshallian consumer surplus.

YEAR	R	R^2	Adjust. R^2	F	Sig (99%)	Durbin-Watson	Pearson corr. coef.	Kolmog. Smirnov (Z)	atc (weighted)	mtc	MCS
1997	0.850	0.722	0.667	13.013	YES	1.830	-0.048	0.661	27.29	356.82	**18.84**
1998	0.901	0.812	0.775	21.612	YES	2.256	-0.075	0.629	19.88	356.82	**27.36**
1999	0.853	0.728	0.680	15.15	YES	1.665	-0.058	0.348	27.30	356.82	**21.27**
2000	0.926	0.857	0.803	15.981	YES	1.981	-0.096	0.698	25.64	356.82	**18.11**
2001	0.923	0.853	0.823	28.979	YES	1.679	-0.077	0.653	25.39	356.82	**28.81**
2002	0.898	0.806	0.773	24.856	YES	2.270	0.434	0.406	25.32	356.82	**22.53**
2003	0.850	0.722	0.673	14.751	YES	2.305	-0.076	0.574	24.50	356.82	**28.07**
2004	0.918	0.842	0.809	24.951	YES	1.953	-0.064	0.52	26.20	356.82	**15.42**
2005	0.836	0.698	0.623	9.254	YES (*)	2.010	-0.244	0.407	18.73	356.82	**12.23**

(*) Significant at the 95% significance level.

Table 2. Ordinary least squares estimates for recreational harvesting of edible wild mushrooms in 'Pinar Grande' (Soria-Spain): demand parameters.

YEAR	A				β_1				β_2				β_3			
	Value	Stand. error	t-value	Sig (99%)	Value	Stand. error	t-value	Sig (99%)	Value	Stand. error	t-value	Sig (99%)	Value	Stand. error	t-value	Sig (99%)
1997	-3.623	1.234	-2.937	YES	34.692	5.597	6.198	YES	0.045	0.086	0.520	NO	-0.08	0.088	-0.86	NO
1998	-6.084	1.344	-4.528	YES	48.803	6.591	7.405	YES	0.204	0.095	2.159	YES (*)	0.06	0.116	0.48	NO
1999	-4.276	1.130	-3.783	YES	46.242	7.112	6.502	YES	0.078	0.077	1.017	NO	-0.01	0.101	-0.08	NO
2000	-4.868	1.331	-3.658	YES	47.509	7.296	6.511	YES	0.087	0.086	1.001	NO	0.06	0.126	0.51	NO
2001	-5.244	1.398	-3.750	YES	54.197	5.935	9.132	YES	0.134	0.073	1.849	YES (**)	-0.04	0.073	-0.59	NO
2002	-5.972	1.148	-5.201	YES	52.924	7.011	7.549	YES	0.173	0.066	2.632	YES	-0.07	0.088	-0.78	NO
2003	-4.481	1.366	-3.281	YES	50.065	7.947	6.300	YES	0.084	0.075	1.122	NO	0.00	0.094	-0.03	NO
2004	-5.179	1.202	-4.309	YES	48.975	5.974	8.198	YES	0.072	0.061	1.179	NO	0.08	0.060	1.34	NO
2005	-3.704	0.856	-4.327	YES	38.799	12.754	3.042	YES (*)	-0.07	0.285	-0.26	NO	-0.42	0.410	-1.01	NO

(*) Significant at the 95% significance level (**) Significant at the 90% significance level

The models were evaluated using several criteria, including explanatory power (adjusted R^2) and significance (F-value). In the first case, the explanatory power is very high for all years with adjusted R^2 between the values of 0.623 (2005) and 0.823

(2001). In the second case, *F*-ratio value indicated that all models were significant overall at the 1% level, except for 2005, significant at the 5% level.

With respect to the price or travel cost coefficients estimates for each of the nine annual models, were consistent with demand theory, in that the quantity of visitors per 1000 inhabitants in the area was inversely related to price or travel cost. Intercept and travel cost coefficients are significant at the 1% level for all years, except 2005 travel cost coefficient that is significant at the 5% level. In relation to other coefficients, the major limitation of ZTCMs is the loss of data variation due to zonal averaging that results in insignificant social and demographic variables (Poor & Smith, 2004), as in this case. For example, provincial per-capita income only was significant in three years, one at 1% level (2002), one at 5% level (1998) and one at 10% level (2001). On the other hand, the sign of these coefficients is positive and is the expected according to consumer behaviour (except in 2005). However, the number of mycological societies was insignificant for all years and it sign is negative which goes expectations.

The models were tested for heterodedasticity because travel cost models with unequal populations often lack homocedasticity, which is caused by the difference in visitation rates from zones with larger populations being greater than in zones with smaller populations (Bowes & Loomis, 1980; Vaughan *et al.*, 1982). This problem is also common when there are variations in visitation rates between zones(Christensen & Price, 1982). The correlation between dependent variable predicted adjusted values and standardised residuals regression, using Pearson's correlation coefficient, was insignificant at the 95% significance level. Heterodedasticity is not, therefore, considered to be a problem for this analysis.

The models were also tested too for autocorrelation, using the Durbin-Watson test, and residuals normality absence[3], using Kolmogorov-Smirnov test with the standardised residuals sample. In all years the applied test rejected the presence of these problems, and so the models are believed to be valid for prediction making and the Marshallian consumer surplus is calculated in terms expressed in formula number 6.

The results of the integration process, between actual and maximum travel cost (*atc* and *mtc*), for all years are presented in final columns of Table 1. The range of the consumer surplus varies between the 12.23€ per car in 2005 (minimum MCS) to

[3] This aspect could be a problem with small samples like in this case.

28.81€ per car in 2001 (maximum MCS) where the average of the period reaches a value of 21.40€.

According to face to face surveys conducted in the autumn seasons in Pinar Grande (García-Cid, 2002), the average number of people per local car was 2.02 (1.8 adults and 0.22 children) and 2.57 per car coming from outside of Soria (2.29 adults and 0.28 children). The weighted average per car in the period 1997-2005 is 2.28[4] (2.03 adults and 0.25 children). The consumer surplus per harvester varies between the 6.05€ per adult person in 2005 to 14.19€ in 2001, where the average of the period reaches a value of 10.49€.

Finally, the results of the ordinary least squares estimation of the explanations factors of the Marshallian consumer surplus model, described by equation number 7, are presented in Table 3.

Table 3. Ordinary least squares estimates for Marshallian consumer surplus of recreational harvesting of edible wild mushrooms in 'Pinar Grande' (Soria, Spain): summary model and parameters.

Summary model	Value	Parameters	Value	Standard error	t-value	Sig (95%)
R	0.843	α´	3.207	0.633	5.064	YES
R2	0.711	β1´	0.009	0.003	2.643	YES
Adjusted R^2	0.538	β2´	0.001	0.003	0.238	NO
F	4.113	β3´	-0.362	0.764	-0.827	NO
Sig (95%)	YES (*)					
Durbin-Watson	2.748					

(*) Significant at the 90% significance level.

In terms of goodness-of-fit statistics for all tested specifications of the model, the exponential model offered the best adjustment with a value of the adjusted R^2 of 0.538. The F ratio test indicates that the results are significant at the 10% level. In terms of estimated coefficients, only fit production in kilogrammes per hectare of *Boletus edulis* was significant (5% level) and positive and, therefore, consistent with the expected. Other variables, like retarded fit production and cost of petrol was non-significant. These variables therefore do not influence the harvesters' well-being in any significant way. In

[4] The data are coherent with Schlosser and Blatner (1992). These authors found an average of 2.2 harvesters per car in Oregon National Parks.

this case, it is only important if the visitor finds edible wild mushrooms. In addition, a well-informed harvester only travels if a certain quantity of this forest production is expected to be collected, and their well-being will increase in an exponential form with their harvest. Therefore, recreational harvesters visit more to look for edible wild mushrooms in propitious season because the fundamental variable to travel is find edible wild mushrooms. That is to say, there is a negative relationship between the wellbeing of recreational harvesters and the value of the edible wild mushrooms they picked compared to their price in local markets[5], since in high season prices tend to drop. This behaviour differs from commercial harvesters who prefer to collect at high prices although the quantity would be reduced, increasing their income wherever possible[6].

4 DISCUSSION AND CONCLUSIONS

The knowledge of the demand function is fundamental for the management of this resource. Its estimation allows us to calculate the maximum willingness to pay, in the form of Marshallian consumer surplus, through a hypothetical regulation of edible wild mushrooms picking, the access permits that increase travel costs. In the case of '*Pinar Grande'* the average of the period under study reaches a value of 21.41€ per car (10.49€ per adult person) and varies between 12.59€ per car (6.05€ per person) in 1995 and 28.73€ per car (14.91€ per person) in 2001. These values depend on the seasonal variations in production of edible wild mushrooms in this zone. In particular, the season, considered in terms of edible wild mushroom availability in the forest, accounts for approximately 54% of the Marshallian consumer surplus of recreational harvesters.

Several authors find similar values applying this methodology to other recreational activities in natural spaces in Spain during the study period. For example, using ZTCM, Campos and Riera (1996) estimate the MCS in 8.41€ per visitor to Monfragüe Natural Park and Riera and Farreras (2004) in 37.06€ per car in tourism in the Basque Country[7]. Using ITCM, Pérez and Pérez *et al.* (1998), Saz (1996) and García and Colina (2004) calculate these values in 14.21€, 15.24€ and 15.55€ per visitor

[5] In favourable seasons there is a negative relationship between the production of edible wild mushrooms and their price, in the sense expressed by the economic theory.

[6] Its depends on the price-elasticity of edible wild mushrooms demand in the markets.

[7] These authors use out-of-pocket cost like independent variable.

respectively to several natural parks in Spain (Posets Maladeta, L´Álbuera and Somiedo).

The comparison is paradoxical with the results of edible wild mushrooms TCM studies in Spain. For example, Mártinez de Aragón (2005), using ITCM estimates in 38.22€ for each person who harvests in Solsones area (Catalonia). The explanation could be the use of out-of-pocket cost as an independent variable instead petrol cost as in our case. Martínez Peña (2003) finds bigger differences in the same study area (Pinar Grande) with 188€ per car. The source of divergence could be due to the use of full-car-running cost, the absence of local harvesters in the sample or econometrics aspects during the process of estimation of demand function.

We can also compare the range of estimatedMarshallian consumer surplus of recreational harvesters (6.05- 14.91 euros) with the daily recreational licence cost in regulated areas (5 euros). This demonstrates that there is an important difference which could be incorporated into tax management and the regulation of the resource via harvest fees.Another matter is the social response to an increase in the cost of licences, which would need investigating beforehand.

In conclusion, if the consumer surplus depends on edible wild mushroom production, so too would the hypothetical harvest fee. The found exponential relation could serve as an aid to managers of the resource when deciding upon the rate. Thus, for low edible wild mushrooms productions in the forest, lower consumer surpluses for harvesters and vice versa. For low edible wild mushroom production, the fees do not have to be very high but could grow substantially according to improvements in the mushroom season.

5 APPENDIX

$$MCS = \int_{atc}^{mtc} e^{\hat{\alpha}+\frac{\hat{\beta}_1}{TC}} dTC = \int_{atc}^{mtc} e^{\hat{\alpha}} e^{\frac{\hat{\beta}_1}{TC}} dTC = e^{\hat{\alpha}} \int_{atc}^{mtc} e^{\frac{\hat{\beta}_1}{TC}} dTC$$

$$Variablechange \rightarrow \frac{1}{TC} = t \Rightarrow dt = -\frac{-dt}{t^2}, t_1 = \frac{1}{mtc}, t_0 = \frac{1}{atc} \Rightarrow$$

$$MCS = e^{\hat{\alpha}} \int_{\frac{1}{atc}}^{\frac{1}{mtc}} e^{\hat{\beta}_1 t} (dt/t^2) = -e^{\hat{\alpha}} \int_{\frac{1}{atc}}^{\frac{1}{mtc}} \frac{e^{\hat{\beta}_1 t}}{t^2} dt = e^{\hat{\alpha}} \int_{\frac{1}{mtc}}^{\frac{1}{atc}} \frac{e^{\hat{\beta}_1 t}}{t^2} dt = (I)$$

$$f(t) = e^{\hat{\beta}_1 t};\ f'(t) = \hat{\beta}_1 e^{\hat{\beta}_1 t};\ f''(t) = \hat{\beta}_1^2 e^{\hat{\beta}_1 t};\ f'''(t) = \hat{\beta}_1^3 e^{\hat{\beta}_1 t}; \ldots;\ f^{(n)}(t) = \hat{\beta}_1^n e^{\hat{\beta}_1 t}$$

$$f(0) = 1;\ f'(0) = \hat{\beta}_1;\ f''(0) = \hat{\beta}_1^2;\ f'''(0) = \hat{\beta}_1^2; \ldots;\ f^{(n)}(0) = \hat{\beta}_1^n$$

$$f(t) = e^{\hat{\beta}_1 t} = 1 + \frac{\hat{\beta}_1}{1!} * t + \frac{\hat{\beta}_1^2}{2!} * t^2 + \ldots = \sum_{n=0}^{\infty} \frac{\hat{\beta}_1^n}{n!} * t^n \ (folowingMcLaurin)$$

So we can integrate (I) in the following way:

$$g(t) = \frac{e^{\hat{\beta}_1 t}}{t^2} = \sum_{n=0}^{\infty} \frac{\hat{\beta}_1^n}{n!} * t^{n-2}$$

If G(t) is the primitive of g(t) then,

$$G(t) = -\frac{1}{t} + \hat{\beta}_1 \ln t + \frac{\hat{\beta}_1^2}{2!} * t + \frac{\hat{\beta}_1^3}{3!} * \frac{t^2}{2} + \ldots = -\frac{1}{t} + \hat{\beta}_1 \ln t + \sum_{n=0}^{\infty} \frac{\hat{\beta}_1^{n+2}}{(n+2)!} * \frac{t^{n+1}}{n+1}$$

So, following Barrow:

$$(I) = e^{\hat{\alpha}} \int_{\frac{1}{mtc}}^{\frac{1}{atc}} g(t) dt = e^{\hat{\alpha}} [G(t)]_{\frac{1}{mtc}}^{\frac{1}{atc}} = e^{\hat{\alpha}} \left[G\left(\frac{1}{atc}\right) - G\left(\frac{1}{mtc}\right) \right] =$$

$$e^{\hat{\alpha}} \left[\begin{array}{l} \left(-atc + \hat{\beta}_1 \ln \frac{1}{atc} + \left(\frac{\hat{\beta}_1^2}{2!}\right) * \left(\frac{1}{atc}\right) + \left(\frac{\hat{\beta}_1^3}{3! * 2}\right) * \left(\frac{1}{atc^2}\right) + \ldots \right) - \\ (-mtc) + \hat{\beta}_1 \ln \frac{1}{mtc} + \left(\frac{\hat{\beta}_1^2}{2!}\right) * \left(\frac{1}{mtc}\right) + \left(\frac{\hat{\beta}_1^3}{3! * 2}\right) * \left(\frac{1}{mtc^2}\right) + \ldots \end{array} \right] =$$

$$e^{\hat{\alpha}} \left\{ (mtc - atc) + \hat{\beta}_1 \ln \frac{mtc}{atc} + \left(\frac{\hat{\beta}_1^2}{2!}\right) * \left[\left(\frac{1}{atc}\right) - \left(\frac{1}{mtc}\right) \right] + \left(\frac{\hat{\beta}_1^3}{3! * 2}\right) * \left[\left(\frac{1}{atc^2}\right) - \left(\frac{1}{mtc^2}\right) \right] + \ldots \right\}$$

Then

$$MCS = e^{\hat{\alpha}} \left\{ (mtc - atc) + \hat{\beta}_1 \ln \frac{mtc}{atc} + \sum_{n=0}^{\infty} \left[\frac{\hat{\beta}_1^{n+2}}{(n+2)! * (n+1)} * \left(\frac{1}{atc^{n+1}} - \frac{1}{mtc^{n+1}} \right) \right] \right\}$$

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ANEXO

Artículos publicados (formato revista)

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A sampling method for estimating sporocarps production of wild edible mushrooms of social and economic interest

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Abstract

This study introduces a new approach to determine and assess total mushroom production as well as to partitioning off this gross production into: non-harvested unripe production; non-harvested ripe production; harvested production; production eaten by fauna; and damaged production.

Nine 300 m-long transects were established in the studied area. The sampling method was carried out in 2004, 2005 and 2006, but 2006 was the most productive year. In this year, a production of 5.37 kg/ha was estimated for *Boletus edulis* in 2006 of which 24% of *Boletus edulis* gross production was harvested, 26% was damaged and 15% was recorded as ripe production. The distribution of the gross production by classes permits knowing essential aspects regarding edible mushrooms management including which pressure is undergoing the fungal resource (due to harvesting or grazing), quantity and quality of the production or whether the species regeneration is guaranteed at any moment.

This information allows us to ascertain the fungal resources conservation state and undertake a management and regulatory process for edible mushrooms in the sampled areas.

Key words: Forest management; Mushrooms; Mycological inventory; Sampling; Sporocarps production.

Resumen

Estimación de la producción de carpóforos de hongos silvestres comestibles

El método de muestreo mediante marcaje y seguimiento de carpóforos permite separar la producción bruta estimada en los diferentes tipos de producción que la componen: producción recolectable inmadura, producción recolectable madura, producción recolectada, producción consumida por fauna, producción malograda.

Para llevar a cabo el estudio se establecieron 9 transectos de 300 metros de longitud. Este procedimiento de muestreo se empleó durante los otoños de 2004, 2005 y 2006, aunque 2006 fue el más productivo. En este año se estimó una producción bruta de *Boletus edulis* de 5,37 kg/ha de la que, el 24% fue recolectada, el 26% resultó malograda y el 15% se registró como producción madura. La distribución de la producción bruta permite conocer, entre otros, la presión, recolectora o ganadera, a la que está sometido el recurso, la cantidad y calidad de la producción y las garantías de regeneración existentes en cada momento.

En general, esta información, nos permite determinar el estado del recurso micológico y emprender, desde la base y de forma fundamentada, un proceso de ordenación y regulación del recurso en la zona muestreada.

Palabras clave: Gestión forestal; Hongos; Inventarios micológicos; Muestreo; Producción de carpóforos.

1. Introduction

Mycological resources are often underestimated (Oria de Rueda Salgueiro *et al.*, 1991; Díaz Balteiro *et al.*, 2003), but growing interest in their use has increased the value of edible mushrooms. In the past, harvesting wood had been considered to be the most important resource to be collected from forests in Spain. Today, the revenue from mushroom collection is beginning to approach the return typically expected from timber

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(Marraco and Rubio, 1992). The harvesting and selling of edible wild mushrooms aid rural development (Boa, 2004) by providing an additional source of income for local inhabitants.

According to a recently published FAO study, 2166 species of wild edible mushrooms are known worldwide and 470 more have medicinal properties. This clearly demonstrates the economic importance of the mushrooms and their relevance as a food source (Boa, 2004).

Edible wild mushrooms are harvested, consumed and marketed in more than 80 countries worldwide, with several million tonnes harvested annually, valued at up to 2 billion dollars (1.35 billion euros) (Boa, 2004).

On the Iberian Peninsula, the amount of commercially harvested *Boletus edulis* species complex has risen to 8,000 tonnes and the amount of *Lactarius deliciosus* to 20,000 tonnes (Oria de Rueda Salgueiro, 1989).

In Castilla y León the average gross annual production for edible wild mushrooms of social and economic interest was been estimated to be 34,000 tonnes (excluding the *Tuber* genus), produced in an area of 4.5 million hectares (Martínez-Peña *et al.*, 2007). About 54% of the population in Castilla y León picks mushrooms that means a potential of 567,715 local harvesters (Martínez-Peña *et al.*, 2007). Taking into account this potential harvest capacity for the region, up to 65 million euros could be generated as direct incomes for the local harvesters by marketing the main commercial species. Mushrooms also feature on the menus of 55% of restaurants in rural areas of Castilla y León and 54% of accommodations in rural areas have mushrooms harverters among their clients (Martínez-Peña *et al.*, 2007).

These figures clearly show the important role that mushroom harvesting and myco-tourism play in the social and economic development of rural areas in Castilla y León.

The growing value of mycological resources has caused an increase in the amount of mushroom harvesters who often exploit the resources to such an extent that the mycological productivity and diversity becomes endangered (Arnolds, 1991; Boa, 2004). In spite of this, there are some authors who believe the impact of mushroom harvesting on sporocarp production is insignificant (Egli *et al.*, 2006). Faced with this situation of endangerment it is necessary to begin a process leading to the sustainable exploitation of the resource, based on studies aimed at obtaining exhaustive knowledge about the biology, ecology and productivity of edible wild mushrooms of social and economic interest in the region (López *et al.*, 2005).

Quantifying the production of wild mushrooms through mycological inventories is essential in order to identify the communities of fungal macrocmycetes in the sampled area. The production of sporocarps is influenced by a multitude of biotic and abiotic factors that considerably vary though time and space. This lack of uniformity in production makes the design and the performance of mycological inventories difficult and obligates to adapt the sampling procedure to the conditions of the area, the species sampled and the sampling objectives (Vogt *et al.*, 1992).

All studies about production and diversity of mushroom populations and communities rely on an inventory stage centred on sporocarps (Ohenoja, 1988; Peter *et al.*, 2001; Taylor, 2002; Egli *et al.*, 2006), mycorrhizae (de Roman and de Miguel, 2005), sporocarps and ectomycorrhizae (Clavería, 2007) or mycelium in the soil (Suz *et al.*, 2006; Parladé *et al.*, 2007).

Methods used in sporocarps inventories varie according to the different authors and the peculiarities of their studies, but sampling units used are mainly plots and transects. Fenced plots are used to estimate mycological gross production since there are no external influences (Ohenoja, 1989; Bonet *et al.*, 2004; Fernandez-Toiran *et al.*, 2006). Otherwise, line-transect method are often used in mycological inventories because of its high spatio-temporal variability (Wilkins and Patrick, 1939). Usually, sampling efficiency is related to the size of the sampled area. As transects sampled area is greater than plots the sampling efficiency is also greater (Richardson, 1970).

The objective of this study is to propose a sampling method for estimating mycological production, based on permanent transects of variable width and on marking and monitoring all found sporocarps. Unlike other sampling methods, our methodology allows for the break down of gross production and gives detailed information about the state of the resource.

Other easier and more economical methods to manage the main edible wild mushroom species of social and economic interest could be develop from the information generated with this sampling method. The aspects that we must take into account are:

1. Harvesting and grazing pressure: when present, pressure from mushroom harvesters and livestock need to be identified and considered in order to better estimate the gross production and assess current state of conservation of the mycological resource.

2. Width of transect: to set the maximum width for all the sporocaps to be detected.

2. Materials and Methods

2.1. Description of the study area

The sampling method was used in transects located on the thalwegs of Pinar Grande, a public forest situated in the northern part of the Sistema Ibérico mountain range, in the region of Pinares (Soria). The study area is comprised of 1,749.6 hectares of pure Scots pine (*Pinus sylvestris* L.) stands.

Pinar Grande has over 12,500 ha and constitutes a basin of gentle orography, is orientated from west to east and varies in altitude from 1,097-1,543 m. The parent materials of the forestland area comprise siliceous conglomerates, quartzite and sandstone from the Lower Cretaceous period. Soils are brown acid, ferriluvic or ferriargiluvic, with a pH range of 3.8 to 5.6, of a sandy to sandy loam texture with low water retention properties and low soil fertility. Phytoclimatically it belongs to the true nemoromediterranean subtype $VI(IV)_2$ (Allué, 1990). Average annual precipitation, according to data from the meteorological station "El Amogable", is 864.8 l/m^2. Average annual temperature measured at "El Amogable" is 8.8ºC.

According to the 2007 livestock census, Pinar Grande is home to 600 cattle and 700 sheep that graze freely over an area of 6,500 ha. Therefore, the pressure due to livestock in Pinar Grande is therefore 11 cattle unit/km^2. In addition, pressure from game animals amounts to 2.53 roe deer/km^2 and 0.94 wild boar/km^2 while deer is nearly absent (Calvo Vacas and Díez Martínez, 1990).

The pressure from mushroom harvesters varies annually; in 2006 the average daily amount measured over a weekend was nine harvesters/km^2, rising to a maximum of 21 harvesters/km^2, calculated by following the methodology of Martínez-Peña (2003).

2.2. Sampling

This sampling method is valid for all species of epigeous macromycetes, although in practice and due to the laboriousness of data collection, the sampled species were those of greater social and economic interest in the study area. In the case of Pinar Grande, the sampled species was *Boletus edulis* due to its economical importance in the county. Hypogeous species were not sampled.

Nine permanent transects measuring 330 m in length were established. The distribution of the sample units was carried out using random and stratified sampling (de Vries, 1986). Stratification was based on forest age so three transects were placed in each differently aged stand (<30 years; 31-70 years; >71 years) and were sampled weekly throughout the autumn, from September to November, for three years (2004, 2005 and 2006).

Each transect was established with numbered trees, in such a way that from each tree along the transect both the next tree and the previous one were visible. Each transect was defined by the central line, that is, the imaginary line that links the consecutive trees.

The width of each transect varies, amongst other factors, according to the species, the slope or the density of the shrub strata. This width can be calculated from all sporocarps positions after sampling had been carried out. Each colony, sporocarps separated among themselves less than 1.5 m, must be located by measuring the distances between the colony itself and both of the trees between which it is situated, taking into account if it is found on the right or the left of the central line of the transect. As the transects are permanent, the distances between every two consecutive trees along the transect were fixed and are measured when the transects were set up. In this way a triangle is formed whose vertices coincide with the sporocarp colony and also the two trees along the transect between which the colony is found.

With these parameters and Heron's formula, which determines the area of a triangle if the three sides are known, the perpendicular distance from the colony to the central transect line (d) can be calculated.

$$p = \frac{a+b+c}{2} \qquad r = \sqrt{\frac{(p-a)*(p-b)*(p-c)}{p}} \qquad d = \frac{2*r*p}{c}$$

Where "*a*" and "*b*" are the distances between each colony and both of the trees between which it is situated and "*c*" is the distance between two consecutive trees.

The calculation of the width of the transects is based on the detectability of the sampled species. Emlen's method is used to set the detectability coefficients in terrestrial vertebrate census (Tellería, 1986).

The different perpendicular distances calculated for each species are analysed to set a band series of the same width where the detectability diminishes from the first band to the last band. This method assumes that all colonies will be seen in the first band and none will be found any further than the maximum distance of the outermost band.

2.3. Description of the sampling procedure

The main peculiarity of this sampling method consists in the marking, locating and monitoring of the sporocarps seen to know their development over time.

Each transect is sampled by locating all the specimens of the mushrooms species found on either side of the central line, regardless of the distance they are found. Once each sporocarp has been sighted data are collected in the following way:

The sporocarp is firstly identified by two numbers, one indicating the colony to which it belongs and the other numbering each sporocarp. This identification is used to label a small stake poked in the ground next to the sporocarp.

The size of the sporocarp cap is then measured in cm and, if necessary, how ripe it is.

The distance is measured from the centre of the colony to each one of the two trees between which the colony has been located. It is also noted if the sporocarp is found to the right or to the left of the central line of the transect.

The recorded sporocarps in the previous sampling should be located to register their evolution, including: the diameter and ripeness if the specimen has continued to develop; recording it as damaged if it has been trampled on, has diminished in size or has been half eaten; or the cause of its disappearance if it cannot be found (harvested or eaten by fauna), as detailed in Table 1.

2.4. Diameter-weight regression and determining ripeness

The sporocarps remain on the study site because they are never collected by the samplers. The weight of each sporocarp is therefore obtained from the cap diameter by using linear regressions (Ohenoja, 1984). These regressions are obtained from the biometric study of a representative sample of sporocarps of the sampled species, selected at different stages of development in the study area.

Table 1. Signs to explain sporocarp disappearence and to identify the agent involved

TYPE OF PRODUCTION	SIGNS-OBSERVATIONS
Harvested production	- Remains of the mushroom left when cleaned by harvesters. - Mushroom stalk cleanly cut by a knife. - Absence of sporocarp without signs of having been consumed by livestock.
Production eaten by fauna	- Ground/top layer disturbed. - Remains of an eaten sporocarp. - Teethmarks on stalk/cap of the mushroom.

The average weight of a sporocarp will be calculated with the same sample. The average weight and standard error for *Boletus edulis* is 126±8 g in stands under than 30 years old, 65±3 g in stands understood to be between 31 and 70 years of age and 79±6 g in stands over 71 years old (Ortega-Martínez, 2005).

This sampling method demands a precise division based on the sporocarps ripeness. Ripeness is determined by the spore print. Ripeness can be determined in some species with a change in the colour of the hymenium, while in other species sporulation experiments must be carried out in order to obtain the same outcome. A sporulation experiment is performed using a sample of sporocarps placed with the hymenium facing downwards on a piece of card with a colour that contrast with the spores of the studied species. After a 24 hour period the level of sporulation of each sporocarp can be observed. By relating this parameter with the sporocarp cap diameter a division between ripe and unripe according to the cap diameter is obtained. *Boletus edulis* shows a change in the colour of the hymenium, so white hymenia indicate an unripe state, while greenish-yellow hymenia are characteristic of ripe specimens.

2.5. Calculating production

The gross mycological production (P_B), in kg/ha, estimated with this sampling method is divided into a group of addends that separate it into other types of production (see Figure 1):

$$P_{Bi} = p_i + P_i + R_i + G_i + M_i \quad (1)$$

Where P_{Bi} is the gross production estimated for week i; p_i is the unripe non-harvested production in week i; P_i is the ripe non-harvested production in week i; R_i is the harvested production in week i; G_i is the production eaten by fauna in week i and M_i is the damaged production (trampled, parasitised, uprooted, senescence, etc.) in week i. Each one of these addends can also be subdivided into some groups of components.

The unripe non-harvested production in week i, measured in kg/ha, can be expressed by the following formula:

$$p_i = p^{i}_{i} + p^{`i}_{(i\text{-}1)} + (p^{`i}_{i} - p^{`i}_{(i\text{-}1)}) \quad (2)$$

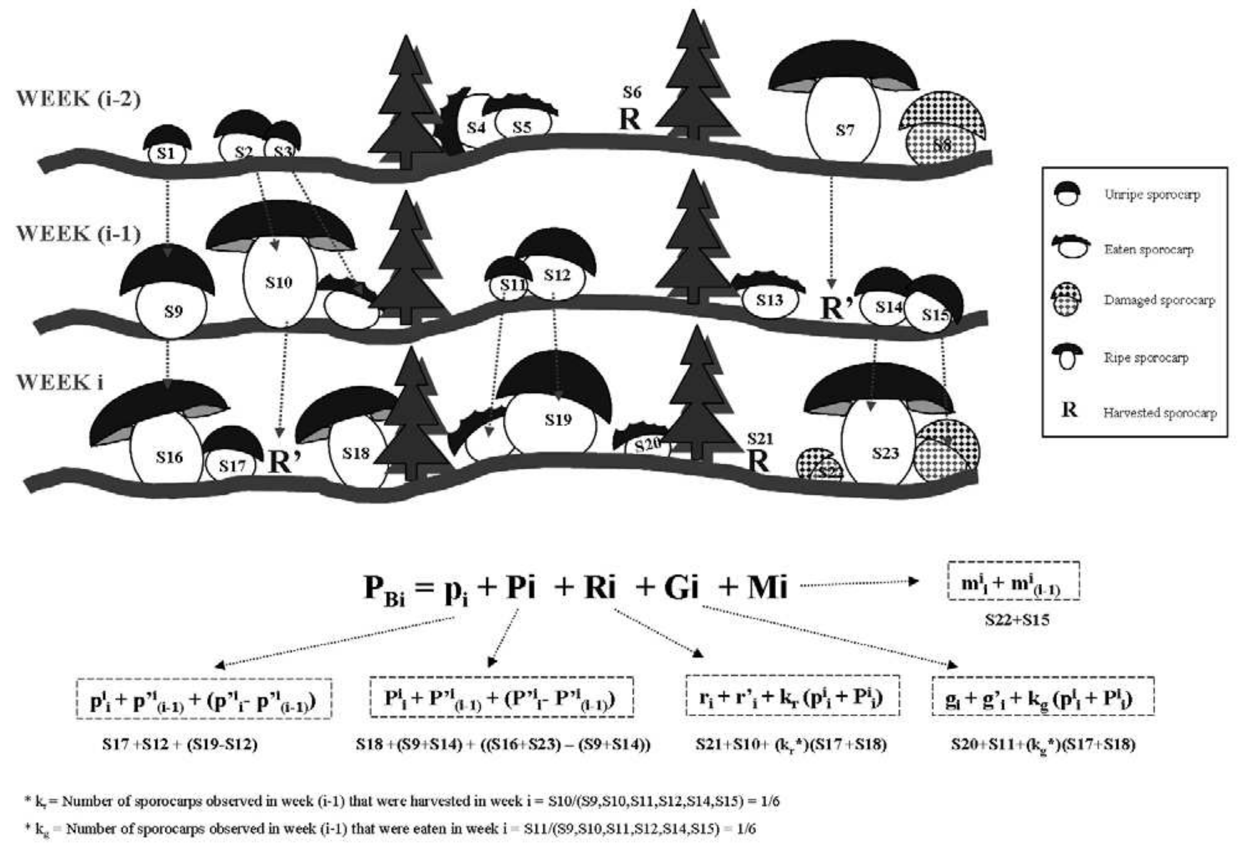

Figure 1. Descriptive setup of the sampling method and its calculation procedure. In the figure, the sporocarps have been numbered and their weight is considered in the formula.

Where p^i_i is the weight of the new unripe specimens sighted in week i; $p'^i_{(i-1)}$ is the weight in week (i-1) of the sporocarps observed as unripe that week and remained unripe in week i; $(p'^i_i - p'^i_{(i-1)})$ is the difference in weight between week i and week (i-1) of the specimens observed as unripe in week (i-1) and remained unripe in week i, thus obtaining the increase in weight from one week to another.

The ripe non-harvested production (P_i) for week i measured in kg/ha can be calculated as:

$$P_i = P^i_i + P'^i_{(i-1)} + (P'^i_i - P'^i_{(i-1)}) \qquad (3)$$

where P^i_i is the weight of the new ripe specimens sighted in week i; $P'^i_{(i-1)}$ is the weight in week (i-1) of the sporocarps observed as ripe or unripe that week and remained ripe or ripened during week i; $(P'^i_i - P'^i_{(i-1)})$ is the difference in weight between week i and week (i-1) of the specimens observed as ripe or unripe in week (i-1) and remained ripe or ripened during week i, thus obtaining the increase in weight from one week to another.

Bearing in mind the work of Egli (Egli *et al*., 2006) it has been accepted that sexual regeneration of *Boletus edulis* is ensured if at least 20% of the gross production remained in situ as P_i.

The harvested production (R_i) for week i is expressed as:

$$R_i = r_i + r'_i + k_r * (p^i_i - P^i_i) \qquad (4)$$

Where r'_i is the weight of the sporocarps observed as harvested in week i and registered the previous week, taking into account the weight they had in week (i-1); r_i are the new specimens observed as harvested in week i, but not previously registered. As these specimens are absent, each one is considered to have the average weight of a sporocarp for each species. It is accepted that there will be a certain amount of specimens harvested in week i that remain undetected due to the lack of any sign of harvesting. To estimate this amount, k_r is calculated, which is the percentage of the number of sporocarps observed in week (i-1) that were harvested in week i. This percentage will be applied to ($p^i_i + P^i_i$) which represents the non-harvested production of new sporocarps observed in week i (regardless of those observed in previous weeks).

In the same way as harvested production, production eaten by fauna (G_i) can be expressed as:

$$G_i = g_i + g_i^{'} + k_g * (p_i^i + P_i^i) \quad (5)$$

The equation for damaged production (M_i) is:

$$M_i = m_i^i + m'^i_{(i-1)} \quad (6)$$

The addend m^i_i is equivalent to the sporocarps that are observed in week i as damaged (trampled on, parasitised, uprooted, etc) and were not previously registered, assigning them the average weight for each species, as in the previous cases. Likewise, $m'^i_{(i-1)}$ are the specimens that were registered the previous week (i-1) and were found as damaged (dry, trampled or become maggoty) in week i, taking into account the weight of this same specimen the previous week.

In order to obtain the value of the gross autumnal production, the terms corresponding to previous weeks ($p'^i_{(i-1)}$ y $P'^i_{(i-1)}$) as well as the increases that the sporocarps present from one week to another (($p'^i_i - p'^i_{(i-1)}$) y ($P'^i_i - P'^i_{(i-1)}$)) must be taken away from the gross weekly production to avoid productions accumulations, obtaining the following equation:

$$P_B = \sum P_i^i + \sum p_i^i + (r_i + k_r * (p_i^i + P_i^i) + \sum (g_i + k_g (p_i^i + P_i^i) + \sum m_i^i \quad (7)$$

3. Results

The sampling procedure was used on the *Boletus edulis* species complex only during the autumn (mycological production in autumn is the highest one of the year) of 2004, 2005 and 2006 on nine transects located in Pinar Grande. Only 2006 information has been considered in this section since mycological production in 2004 and 2005 was very poor.

A total of 136 colonies were located with a total of 200 sporocarps of *Boletus edulis* of which 170 were observed in a good state or damaged, the rest were recorded as harvested (22 sporocarps) or eaten by fauna (8 sporocarps).

By analysing the perpendicular distances (PD) of the 136 colonies found it is observed that within a 2 m width either side of the transect all present sporocarps are detected thus the detectability coefficient (DC) is 1. Taking the 2 m width, four bands within the belt transect were set up, as it is considered that beyond 8m no individuals are detected (DC=0).

The overall detectability coefficient for *Boletus edulis* for a width of 8m either side of the transect is 0.53 and corresponds to the following function of detectability (see figure 2):

$$CD = (1.04871 - 0.128589 * PD)^2 \quad (R^2 = 98\%)$$

where CD is the cap diameter and PD is the perpendicular distance.

The cap diameter-weight regression employed for the conversion of sporocarps of *Boletus edulis* was (Martínez-Peña, 2003):

$$weight(g) = (1.4477 + 1.19504 * cap\_diameter(cm))^2$$

The average gross production obtained (see equation 1) was 5.37 ± 1.33 kg/ha. This gross production is divided in unripe and ripe non-harvested production, harvested production, eaten and damaged production (see figure 3).

It has been estimated that 24% of the production of *Boletus edulis* in Pinar Grande is harvested, while 26% of the gross production became damaged. Only 15% of the gross production of *Boletus edulis* was recorded as ripe production capable of sexual regeneration of the species in the forest.

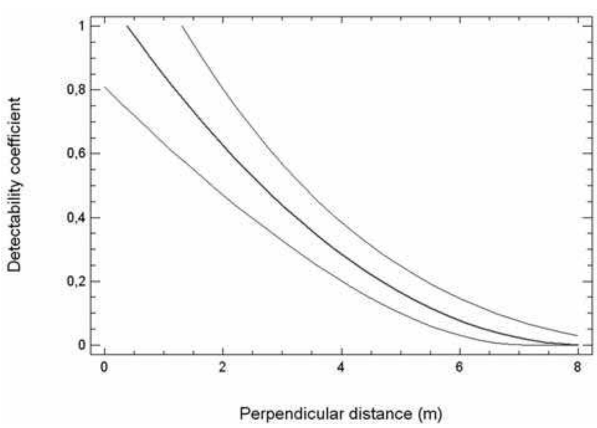

Figure 2. Function of detectability for *Boletus edulis* in Pinar Grande for a transect width of 8 m. The outermost lines represent the 95% upper and lower confidence limits.

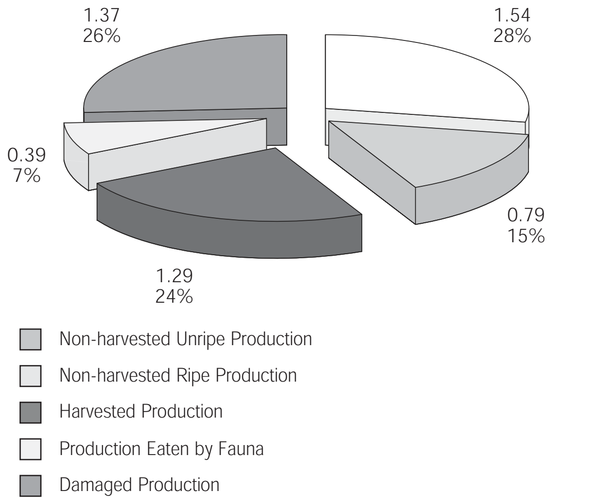

Figure 3. Percentage distribution of average gross production (kg/ha) of *Boletus edulis* in Pinar Grande.

The weekly changes in mushroom production depicted in figure 4 indicate that the weeks during which the production of *Boletus edulis* was higher coincided with those in which the highest number of mushrooms were harvested, showing the largest influx of harvesters occurred when the production was at its highest levels.

According to Table 2, only weeks 43, 46 and 47 had high enough non-harvested production to guarantee regeneration (percentages of gross production higher than 20%).

4. Discussion

The proposed sampling method allows to estimate the gross production of the study area and to separate it into perfectly defined different types of production.

As well as the considerable temporal and spatial variation inherent to fungal fructification, other factors can lead to a quite substantial underestimation of production if not duly taken into account. These factors are harvesters and fauna essentially. Authors such as Richardson (1970), Ohenoja (1984), Ohenoja *et al*. (1984), Mehus (1986) and Hunt and Trappe (1987) highlighted that both agents should be taken into consideration when quantifying mycological production in a forest.

The novelty of this sampling method is that the gross production is separated into its main components. Gross production is easily estimated by using plots and transects with different characteristics (Richardson, 1970; Vogt *et al.*, 1981; Ohenoja and Koistinen, 1984; Mehus, 1986; Ohtonen, 1986; Luoma *et al.*, 2004; Bonet *et al.*, 2004; Kranabetter *et al.*, 2005), although fenced plots are the best way to estimate this production mainly in areas where grazing and harvesting pressures are high (Ortega-Martínez and Martínez-Peña, 2005).

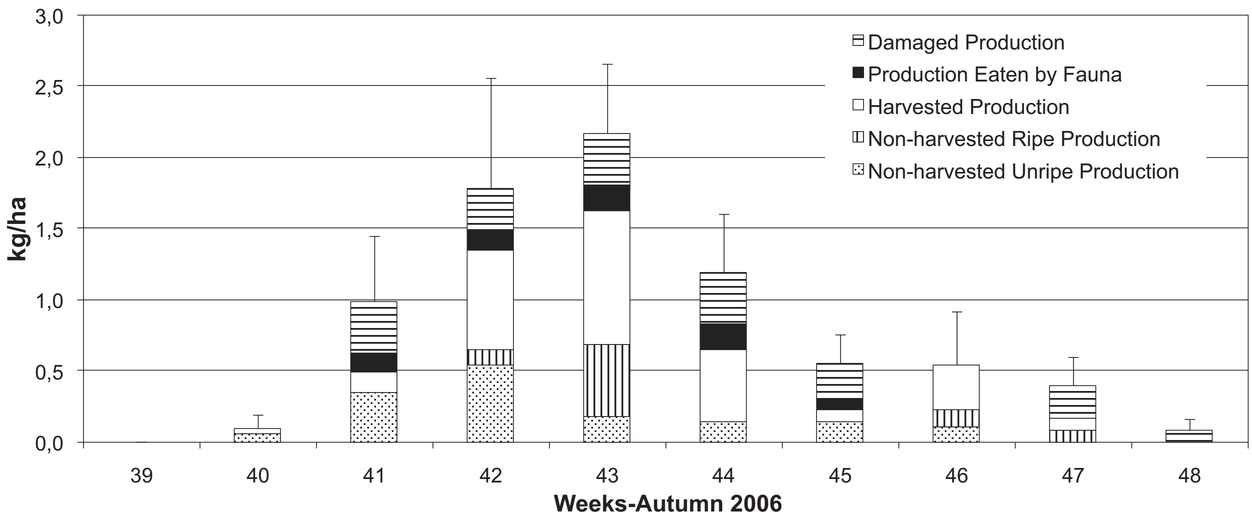

Figure 4. Distribution of gross weekly production. The *x* axis represent the weeks of the year and the *y* axis represents gross production in kg/ha.

Table 2. Weekly percentage of each type of production in 2006

WEEK	UNRIPE NON-HARVESTED (%)	RIPE NON-HARVESTED (%)	HARVESTED (%)	EATEN BY FAUNA (%)	DAMAGED (%)	GROSS PRODUCTION (kg/ha)
39	-	-	-	-	-	0 ± 0
40	69	0	31	0	0	0.09 ± 0.09
41	36	0	14	13	37	0.99 ± 0.46
42	30	6	39	8	16	1.78 ± 0.77
43	8	24	43	9	17	2.17 ± 0.48
44	12	0	43	15	30	1.19 ± 0.41
45	27	0	15	14	45	0.55 ± 0.20
46	19	23	58	0	0	0.54 ± 0.37
47	0	20	24	0	56	0.4 ± 0.20
48	0	0	0	0	100	0.08 ± 0.08

Many authors (Richardson, 1970; Fogel and Trappe, 1978; Luoma *et al*., 2004) have emphasized the influence of fauna on mycological production, clearly demonstrating that in areas where fauna was present, the sporocarps were either completely eaten or nibbled by animals, which causes errors if it is not taken into account when the mycological production is estimated.

The specimens eaten by fauna were recorded in the inventory for calculating the production of matsutake (*Tricholoma magnivelare*) carried out by Luoma *et al.* (2006). These authors observed any signs of soil disturbance, teeth marks or sporocarp fragments in order to conclude that the specimens had been consumed.

Some studies carried out in the Pacific Northwest United States have tried to reduce the influence of harvesters on the estimations of mycological production in different ways (locating plots in remote areas, posting signs, enforcing no-pick regulations or visiting the plots often) (Pilz and Molina, 2002). This kind of measures is not necessary for the proposed sampling method because the information about harvesting pressure is recorded.

To avoid double counting when it comes to recording the sporocarps and to know conclusively their development over time, a small stake is placed in the ground next to each sporocarp. Nara *et al.* (2003) used little flag next to the fungi to identify the sporocarps that had been sighted and to avoid double counting. Other authors have marked sporocarps with a innocuous dye on the cap (Egli *et al*., 2006; Luoma *et al*., 2006).

The weight of each sporocarp is calculated in relation to the cap diameter since the quality of these estimations has been clearly demonstrated in other studies (Liegel *et al*., 1998; Pilz *et al*., 1999).

The proposed sampling method takes place on a weekly basis; an interval of this length is considered by Luoma *et al.* (2006) as optimal to carry out mycological inventories. This periodicity can be adapted to each species if their life cycle is shorter than this interval or they can suffer incessant attacks by insects or other organisms (Richardson, 1970; Mehus, 1986).

The complexity of the data collection is such that it requires skilled labour to be carried out and the duration of the sampling is lengthened considerably (in proportion to the fungal production). This causes an increase of the sampling cost, limits the number of daily repetitions (Fogel, 1981) and can even rule out sampling altogether in particular situations.

The design of any mycological inventory requires the choice of a suitable sampling strategy and sampling effort (Taylor, 2002). This choice will vary, mainly depending on the peculiarities of the area to be sampled (Pilz *et al*., 2002), the proposed objective and the available economic resources. For these reasons, the proposed sampling method will be justified in areas with substantial production of edible wild mushrooms and high harvesting or grazing pressure.

Mycophagous fauna plays an important role in the spores dispersion (Frank *et al*., 2006) that it can be calculated from the percentage of the gross production that is eaten by animals.

Despite certain authors concluding that harvesting does not affect sporocarp production (Pilz *et al*., 2003; Arnolds, 1991; Egli *et al*., 2006), it has been considered that a high percentage of harvested production reveals an excessive exploitation of the resource. It can be assumed that the excessive pressure reduces sporocarp production, if not due to the current harvesting, due to the trampling of harvesters over the area (Egli *et al*., 2006).

The high percentage of damaged production obtained in the autumn of 2006 in Pinar Grande can partially be explained by the relatively abundant rainfall and mild temperatures recorded during the summer and autumn of 2006, favouring the development of dipterous larvae populations, the principal responsible for the sporocarps to become maggoty (Martínez-Peña, 2003).

The offered results and particularly the breakdown of gross production into percentages show the state of conservation and exploitation of the studied species. The interpretation of the results can be simplified to study the percentage of ripe non-harvested production, given that ripe mushrooms present the greatest potential for sporulation by generating the largest amount of spores produced throughout their life cycle, thus guaranteeing sexual regeneration of the species.

With this information, a based management and regulatory plan can be designed. The criteria obtained using the proposed sampling method (not only for *Boletus edulis* but also for other species), along with other environmental information can represent the basis to establish appropriate management and regulatory conditions (number of permits, species that can be harvested, maximum quantities, space and temporary limits for harvesting, etc.).

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SHORT NOTE

Tree age influences on the development of edible ectomycorrhizal fungi sporocarps in *Pinus sylvestris* stands

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Abstract The study of factors influencing the production and development of wild edible mushroom sporocarps is extremely important in the characterization of the fungi life cycle. The main objective of this work is to determine how tree age influences the speed of sporocarp growth of edible ectomycorrhizal fungi *Boletus edulis* and *Lactarius deliciosus* in a *Pinus sylvestris* stand. This study is based on information recorded on a weekly basis every autumn between 1995 and 2008 in a set of permanent plots in Spain. Sporocarps are collected weekly, and as a result, specimens may not have reached their maximum size. The study area is a monospecific *P. sylvestris* stand. Three age classes were considered: under 30 years, between 31 and 70 years, and over 70 years. Sporocarps of *B. edulis* and *L. deliciosus* grow faster in the first age class stands than in the other two, and in the second age class stands, sporocarps are more than 50% smaller. The average weight of the picked *B. edulis* sporocarps clearly varies in the three age classes considered, with its maximum in the first age class (127 g and 6.8 cm cap diameter), minimum in the second age class (68 g and 4.7 cm cap diameter), and showing a relative maximum in the third (79 g and 4.3 cm cap diameter). *L. deliciosus* sporocarps are on average larger in the first age class (48 g and 7.4 cm cap diameter), decreasing in the second (20 g and 5.8 cm cap diameter) and also in the third (21 g and 5.3 cm cap diameter). The results show the influence of tree age in speed of sporocarp growth for the two ectomycorrhizal species.

Keywords *Boletus edulis* · *Lactarius deliciosus* · Stand age class · Scots pine

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Introduction

Edible mycorrhizal mushrooms are not only a gourmet food but also a source of income for collectors (Wang and Hall 2004). In Europe, *Boletus edulis* Bull. and *Lactarius deliciosus* Fr. are considered to be two of the most highly valued edible mycorrhizal mushrooms.

Total annual worldwide consumption of *B. edulis* complex reaches between 20,000 and 100,000 tons (Hall et al. 1998). Important markets include North America, France, Italy, and Germany (Hall et al. 1998). The estimated annual production of *B. edulis* species complex from the autonomous community of Castilla y León (north Spain) adds up to 8,500 tons, being worth approximately 38 million euros (Martínez-Peña et al. 2006–2009).

Even though it is not as widely appreciated as porcini, *L. deliciosus* has consolidated markets in Europe, Asia, and North Africa, where a large amount of those sporocarps are commercialized and comprise a significant source of income (Boa 2004).

Seedlings mycorrhizated with *L. deliciosus* are available in nurseries throughout the world, and the scientific community is making an effort to facilitate the production of seedlings mycorrhizated with *B. edulis* (Águeda et al. 2008b; Ceruti et al. 1987; Duñabeitia et al. 1996; Olivier et al. 1997). Nowadays, both species have to be collected from the wild with variable and unpredictable harvesting from year to year (Cannon and Kirk 2007; Murat et al. 2008).

However, factors influencing sporocarp formation are not yet apparent. Sporocarp formation is probably the most complicated stage in the life cycle of fungi. This situation is even more complex for ectomycorrhizal fungi, which require symbiotic association with a host plant. Fungal and host genes, environmental and physiological conditions, and nutritional state of mycelium and the host trigger sporocarp formation in ectomycorrhizal fungi, but the process is not fully understood to date (Murat et al. 2008).

Host development entails changes in its physiological state, which influence relations with the host's associated fungal ectomycorrhizal community and, consequently, its fructification.

The aim of this study is to establish a relationship between stand age class and the growth of *B. edulis* and *L. deliciosus* sporocarps.

Materials and methods

Study site

The study site is located in a homogeneous *Pinus sylvestris* L. stand known as "Pinar Grande." It is a 12,533-ha area situated in the Sistema Ibérico mountain range, in the inner north-east zone of the Iberian Peninsula. Altitude varies between 1,097 and 1,543 m a.s.l. with dominating west and east orientations.

Soils are acidic brown-earths or illuvial, with marked acid pH (4–5), sandy loam to sandy texture, low holding capacity, and low fertility.

Medium annual rainfall is 865 mm/year, 69 mm/year falling in July and August and 132 mm/year in September and October. Medium annual temperature is 8.8°C, with July being the warmest month (17.4°C). The frost period begins in November and ends in April, with frequent frosts in late spring and early autumn. Scots pines are felled every 100 years. The forests are silviculturally managed by clear cutting with soil movement and sowing.

In this area, 119 species of epigeous macromycetes fungi have been recorded. They belong to 51 genera and more than half are members of *Russula* Pers., *Cortinarius* (Pers.) Gray, *Tricholoma* (Fr.) Staude, *Amanita* Pers., *Lactarius* Pers., *Collybia* (Fr.) Staude, *Cystoderma* Fayod, *Hebeloma* (Fr.) P. Kumm., *Mycena* (Pers.) Roussel, and *Suillus* Gray (Martínez-Peña 2009).

B. edulis and *L. deliciosus* average autumnal sporocarp production in Pinar Grande between 1995 and 2008 by stand age class is detailed in Table 1 (Martínez-Peña 2009).

Sampling design

A random sampling design was performed by stand age, according to the forest management plan: 0–15, 16–30, 31–50, 51–70, 71–90, and over 90 years old. Three plots per age class were installed, providing a total of 18 sampling plots.

Each sampling plot covers a rectangular-shaped area of 150 m^2 (measuring 35×5 m). Its size and form were established in line with previous studies by Fernández-Toirán (1994), Kalamees and Silver (1988), and Ohenoja (1989) that use rectangular plots with a minimum area of 100 m^2. Plots were fenced to prevent harvesting and trampling and were at least 500 m from stands corresponding to another age class.

For the present study, plots were regrouped by age in three categories: under 30 years, between 31 and 70 years, and over 71 years, which represent three clearly different stages in the life of a stand: young, mature, and old.

Sampling was performed on a weekly basis from week 35 to 50 every year from 1995 to 2008, as this period corresponds with most sporocarp emergence. All fully developed sporocarps were collected and identified to species level in the laboratory.

Biometric study focused on two edible ectomycorrhizal fungal species: *B. edulis* and *L. deliciosus*. Speed of sporocarp growth is the analyzed dependant variable. Fresh weight (g) and cap diameter (cm) of each sporocarp collected was recorded for both species. Due to the fact that sporocarps are collected every week, the specimens may have not reached their maximum size.

Data analyses

Statistical analyses were performed using STATGRAPHICS Plus 5.1 (Statistical Graphics Corp., Warrenton, VA, USA).

The effect of age stand in the speed of sporocarp growth for *B. edulis* and *L. deliciosus* was analyzed by the weight that sporocarps reach in 1 week using ANOVA. As data proved to

Table 1 *Boletus edulis* and *Lactarius deliciosus* autumnal sporocarps mean fresh weight production (kg/ha) between 1995 and 2008 in Pinar Grande by stand age class (extracted from Martínez-Peña 2009)

	Pinus sylvestris age class stand (years)			Mean
	Under 30	31–70	Over 71	
Boletus edulis	16.2	84.9	21.9	30.3
Lactarius deliciosus	17.9	3.1	14.9	9.1

be unbalanced, the general linear model procedure was applied. Tukey's multiple rank test was used for the multiple mean comparison (Einot and Gabriel 1975). Data were subjected to a logarithmic transformation for normalization purposes.

Speed of sporocarp growth was also analyzed from the cap diameter that sporocarps reach in 1 week using the Kruskal–Wallis test for comparing medians due to the fact that normal distribution and homogeneity hypothesis were not reached although logarithmic transformation was performed.

Results

B. edulis and *L. deliciosus* data analysis show conclusive results on the impact of stand age class in the speed of sporocarp growth. Standard deviation analyses provide valuable information, although the variable weight had been transformed with a logarithm function to comply with the model assumptions.

The average weight of *B. edulis* sporocarps are clearly different for the three stand age classes considered. The maximum is found in the first age class stand, 127 g, and decreases for other stands, 68 and 79 g, respectively (Table 2 and Fig. 1). *B. edulis* sporocarps that developed under the first age class stand have a larger cap diameter after 1 week (Table 2).

L. deliciosus sporocarps occurring under the first age stand are also of significant weight and are included in the major production stage of the stand (Tables 1 and 3). The maximum is found in the first age class stand, 47 g, and decreases for the other two stands, 20 and 21 g, respectively (Table 3 and Fig. 2). There are not enough data to establish any conclusions regarding cap diameter, but *L. deliciosus* developed under the first stand age class reach larger sizes in 1 week (Table 3).

B. edulis and *L. deliciosus* developed under the first age class stand are heavier than those growing in the two other studied categories. The weight of sporocarps in the second age class is nearly 50% lower than in the first.

Discussion

The variable under evaluation is sporocarp growth in 1 week, as sporocarps are picked every week and not at the end of their development. Both species grow faster when they are associated with pine trees in the first age class.

B. edulis and *L. deliciosus* sporocarps occurring in the first age class are larger than in the rest of the classes and nearly 50% heavier in the first than in the second.

This similar behavior is surprising, considering the great differences between these two species. Firstly, *B. edulis* sporocarps are usually collected in old stands (Dighton and Mason 1985), as they are representative of late succession stages in the ectomycorrhizal fungal community. Conversely, *L. deliciosus* sporocarps are usually collected in young stands, being a typical member of early succession stages. In *Pinus pinaster* Ait. stands, *L. deliciosus* reaches its maximum production in the first and in the last age classes (Ágreda and Fernández-Toirán 2008; Fernández-Toirán et al. 2006).

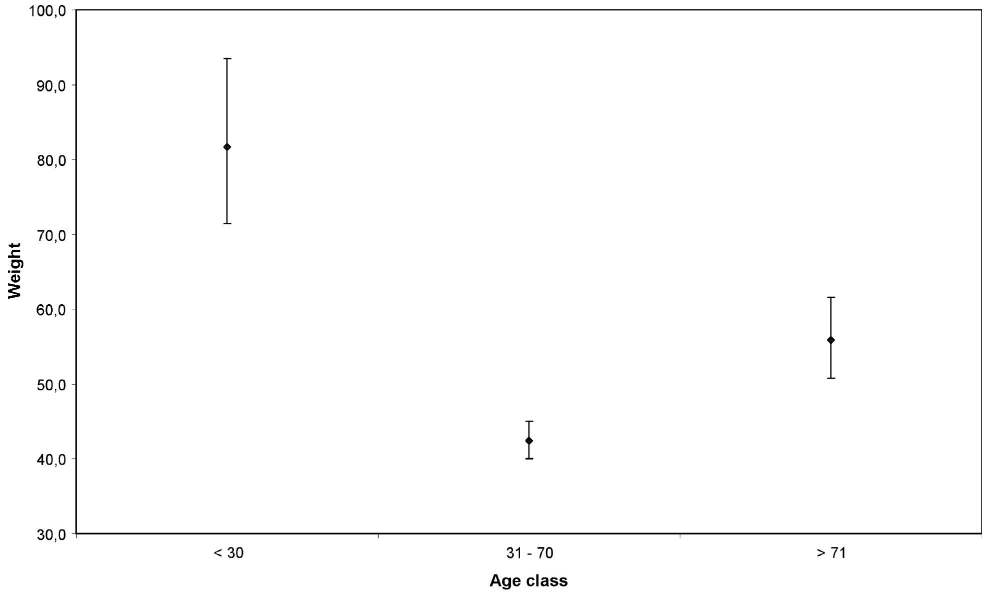
Another main difference between the two species is in their microscopic structures. *B. edulis* is a long-distance species (Agerer 2001), with highly differenced rhizomorphs, formed by hydrophobic hyphae (Águeda et al. 2008a). These features make *B. edulis* highly efficient in transporting water and nutrients to the host and very resistant to ecologic adversities due to its ability to absorb water from deep soil horizons (Lilleskov et al. 2009). *L. deliciosus*, however, is a medium distance subtype smooth species (Agerer 2001), with rhizomorphs formed by undifferentiated hyphae (Uhl 1988). Furthermore, the manner in which a determined species extends in the soil

Table 2 Descriptive statistics for *Boletus edulis* sporocarps weight (g) and cap diameter (cm) reached in 1 week by *Pinus sylvestris* stand age class (years)

	B. edulis sporocarps weight (g)						*B. edulis* sporocarps cap diameter (cm)		
	Under 30		31–70		Over 71		Under 30	31–70	Over 71
Frequency (number of analyzed sporocarps)	138		721		270		124	675	218
	Weight	Log (weight)	Weight	Log (weight)	Weight	Log (weight)			
Mean	126.8	2.1	68.1	1.8	78.9	1.9	6.8	4.7	5.3
Median	92.5	2.0	40.0	1.6	60.0	1.8	6.0	4.0	5.0
Standard deviation	125.9	2.1	83.5	1.9	65.1	1.8	3.8	2.3	2.5

Sporocarps were picked every week during autumn between 1995 and 2008

Fig. 1 Means and Tukey intervals (95%) for *Boletus edulis* medium sporocarp weight reached in 1 week by stand age class. *Pinus sylvestris* stand age classes represented in years and *B. edulis* sporocarp weight in g



and the differentiation of their extramatrical mycelium and rhizomorphs in ectomycorrhizal fungi are extremely important ecological factors for tree performance (Agerer 2001).

Extramatrical mycelium and rhizomorphs are structures that specialized in water and nutrient collection and transport to the host. Mycorrhizal fungi not only cover the portion of the root where absorption of nutrients predominates but also create an extensive and dynamic mycelial network ranging far from the root tip and even into the bedrock (Allen 2009; Lilleskov et al. 2009).

Sporocarp formation is probably the most complex phase in the life cycle of a fungus. It involves dramatic changes of the growth pattern: From a loose mesh of undifferentiated hyphae, a compact multihyphal structure is formed and devoted to sexual reproduction (Murat et al. 2008). The situation is even more complex for ectomycorrhizal fungi, as the sporocarp represents a unique step in a complex life cycle, which requires the symbiotic association with a plant host (Murat et al. 2008).

Abiotic factors, such as light, temperature, humidity, and nutrient availability, exert a decisive influence on sporocarp formation (Erland and Taylor 2002; Murat et al. 2008). These factors could be considered homogeneous in this study. In general, sporocarp development in the ectomycorrhizal fungi is induced by temperature drop, high humidity, neutral or slightly acidic soil, and solar light, although universal conditions triggering development is still unknown.

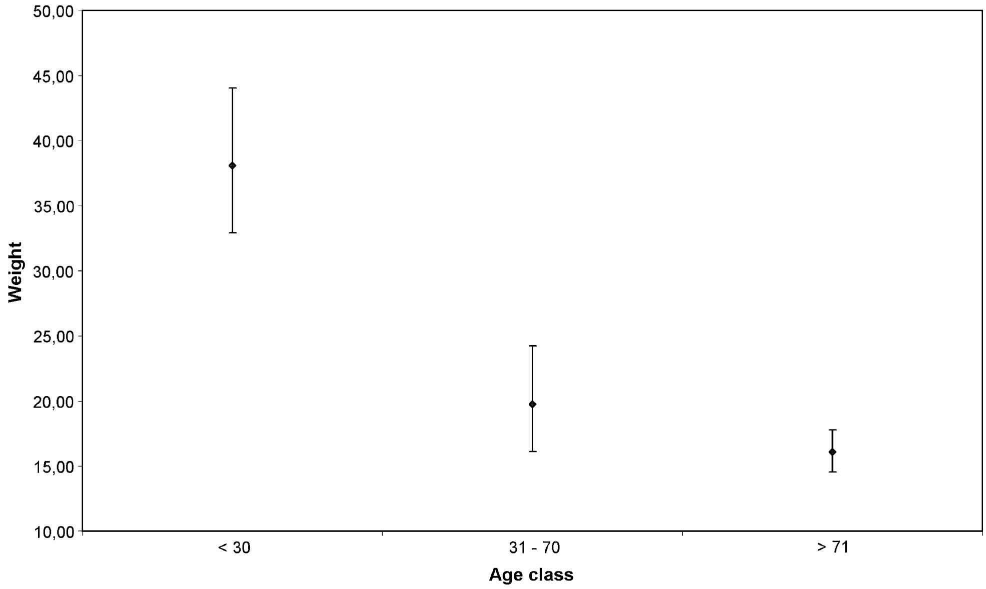
Nutrient availability is a factor of major importance in sporocarp formation. Although the composition of the ectomycorrhizal fungal community on the roots is more or less constant throughout the seasons, hyphae abundance is more dynamic and variable (Koide et al. 2007). Moreover, hyphae abundance of soil mycelia are of vital importance, although there is not always a direct relationship between mycelial volume and sporocarp production (Gardes and

Table 3 Descriptive statistics for *Lactarius deliciosus* sporocarp weight (g) and cap diameter (cm) reached in 1 week by *Pinus sylvestris* stand age class stand (years)

	L. deliciosus sporocarps weight (g)						*L. deliciosus* sporocarps cap diameter (cm)		
	Under 30		31–70		Over 71		Under 30	31–70	Over 71
Frequency (number of analyzed sporocarps)	73		36		149		35	6	48
	Weight	Log (weight)	Weight	Log (weight)	Weight	Log (weight)			
Mean	47.4	1.7	20.3	1.3	21.0	1.3	7.4	5.8	5.3
Median	38.0	1.6	21.5	1.3	17.3	1.2	7.0	6.5	5.0
Standard deviation	35.5	1.6	10.4	1.0	13.1	1.1	2.5	1.6	1.8

Sporocarps were picked every week during autumn between 1995 and 2008

Fig. 2 Means and Tukey intervals (95%) for *Lactarius deliciosus* medium sporocarp weight reached in 1 week by stand age class. *Pinus sylvestris* stand age classes represented in years and *L. deliciosus* sporocarp weight in g



Bruns 1996) as it depends on biotic, abiotic, and physiological factors to a large extent (Erland and Taylor 2002; Smith et al. 2002). In fact, it has been demonstrated that the production of *Tuber melanosporum* Vittad. sporocarps are related to the decrease of extraradical mycelium in the soil (Suz et al. 2008).

Physiological conditions of the host are crucially important factors that trigger sporocarp formation in ectomycorrhizal fungi (Flegg and Wood 1985).

Scots pine in the *Sistema Ibérico* mountain range has its maximum current annual increment in volume when it is 40–60 years old, while maximum current annual increment in height takes place when it is 20–40 years old (Montero et al. 2008). Main root growth stops between 40 and 50 years old (Bravo and Montero 2008). Scots pine in Spain has its maximum relative increment for basal area and volume when it is approximately 10 years old, 11%, decreasing considerably from 20 years old onwards (Montero et al. 2008). Considering these facts, it could be reasoned that host photosynthetic activity is higher when its growth is at its maximum, namely at the end of the first age class for height and basal area increment and the second age class for volume increment.

Trees require more nutrients in their early development phases when growth rates are faster. The fungus could be using these circumstances to its own advantage as it is not capable of surviving without a host and can use more nutrients, complex or otherwise, in the development of its sporocarps.

Some authors found less sporocarp biomass in old-growth stands than in younger stands (Bonet et al. 2010; Dahlberg and Stenlid 1994; Smith et al. 2002). Although those studies analyzed sporocarp biomass, not speed of growth, their results could be explained in a similar way to those presented here.

Bonet et al. (2010) revealed that stand basal area is a strong predictor of sporocarp productivity. The basal area associated with maximum sporocarp productivity coincides with the peak of annual basal area increment in the studied pine stand, when the pine trees are 20–40 years old, suggesting that resources needed for tree growth and for sporocarp production come from a common pool.

Similar positive relationships between the photosynthetic rate of the host and speed of sporocarp growth could explain the facts presented here. In the present study, *L. deliciosus* shows a higher speed of sporocarp growth in young stands, when biomass production is at its highest (Table 1). *B. edulis* has a higher speed of sporocarp growth in young stands, while its greatest biomass production is not in young stands (Table 1) because the species is not representative of early succession stages.

A clear mechanistic hypothesis as to why the speed of sporocarp growth might vary according to tree age class cannot be provided. Further investigation is necessary to obtain these results. The study of the sporocarp behavior has allowed us to increase our knowledge of the ectomycorrhizal fungi life cycle and its spatial and temporal variability, providing suitable information to subsequently develop appropriate management tools for this valuable natural resource.

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Estimating the social benefits of recreational harvesting of edible wild mushrooms using travel cost methods

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Abstract

The public demand for recreational harvesting of edible wild mushrooms has risen over the last two decades and currently affects all forestry areas with mycological resources in Spain. The idea of introducing a system of 'user-pays' fees has been conceived as a possible ecosystem management strategy. Valuing the recreational benefits people derive from harvesting edible wild mushrooms may provide some guidance as to how much people would be willing to pay and may also justify future taxes for on harvesters. Environmental valuation methods allow the benefits of this recreation activity to be estimated. In this case, the authors estimate a demand model of recreational harvesting of edible wild mushrooms in '*Pinar Grande'* (Soria, Spain) through the zonal travel cost model, its consumer surplus associated and explanations factors.

Key words: Recreational harvesting of edible wild mushrooms, zonal models, estimated consumer surplus.

Resumen

Estimación de los beneficios sociales de la recolección recreativa de setas silvestres comestibles a través del método del coste del viaje

La demanda de recolección de setas silvestres comestibles ha crecido de forma importante en las últimas décadas afectando en España a todas las áreas con recurso. La idea de introducir un sistema de pago de permisos ha sido concebida como una posible estrategia de regulación del ecosistema. Valorando los beneficios recreativos que genera esta actividad, a través de métodos de valoración ambiental, se podría conocer lo que los recolectores estarían dispuestos a pagar y justificar así la imposición sobre este recurso. En el presente artículo, los autores estiman un modelo de demanda de recolección recreativa de setas silvestres comestibles en "Pinar Grande" (Soria-España) utilizando el método del coste del viaje en su versión zonal. A partir de aquí, se calcula el excedente del consumidor asociado junto con sus factores explicativos.

Palabras clave: Recolección recreativa de setas silvestres comestibles, modelos zonales, excedente del consumidor estimado.

Introduction

The public demand for recreational harvesting of edible wild mushrooms has risen over the last two decades and currently affects all forestry areas with mycological resources in Spain, impacting on private and public forest landowners. Despite its growing social and economic importance as a forestry resource (Díaz Balteiro *et al*., 2003; Martínez Peña, 2003), the harvesting of wild mushrooms continues to be overlooked in forestry management.

Various authors have investigated into the management of mycological resources (Fernández, 1994; Hosford *et al*. 1997; Palm y Chapela, 1997; Martínez

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Peña, 2003, etc.). The idea of introducing a system of 'user-pays' fees, therefore, has been conceived as a possible solution. Since 2003, edible wild mushroom harvesting has been regulated in the forests of the Castilla y León region. In 2006, 60,630 hectares were regulated using the methodology explained below. The regulation of mushroom harvesting is carried out by signposting the areas of harvesting with notices stating where to collect or not, vigilance of harvesters, commercial control and harvester licences ('user-pays' fees).

In forests which are regulated, it is therefore necessary to hold a mushroom harvest licence. This licence could be valid for a day or a year and with two different kinds of licence to choose from according the harvest activity: a recreational harvest licence (for quantities of mushrooms harvested below 3 kg) or a commercial harvest licence (unlimited quantities).

The price for a recreational and daily harvest licence is 5 €. Whereas, the price for a recreational and annual harvest licence is variable, according to the region where the harvester has come from. However these recreational licence prices are not related to the demand generated by harvesters, due to the fact that these functions have not been estimated through environmental valuation methods. These techniques allow the benefits of this recreation activity to be used as guidance for policy makers. Valuing the recreational benefits derived from the harvesting of edible wild mushrooms may provide some guidance as to how much harvesters would be willing to pay and may justify future taxes.

Therefore, the object of this paper is to provide a recreational demand analysis of non-commercial mushroom harvesting in the '*Pinar Grande'*, using travel cost methods.

A wide selection of empirical literature is available on outdoor recreation demand (Brouwer and Spaninks, 1999; Rosemberg and Loomis, 2001; Morrison *et al*., 2002; Amjath and Suryaprakash, 2008; etc.). Much has also been written about "non-timber values" (Balkan and Kahn, 1988; Layman *et al*., 1996, Knoche and Lupi, 2007; etc.) focusing mainly on the recreational aspects of hunting and fishing. Unfortunately this literature lacks estimates of edible wild mushroom harvesting (Starbuck *et al*., 2004). Spain also has a wide array of literature on forest recreation aspects (Riera, 1997; Riera, 2000; García y Colina, 2004; Mogas, *et al*., 2005; etc.), but few studies focusing on "non-timber values" (Martínez Peña, 2003 and Martínez de Aragón, 2005).

Materials and methods

Description of study area

The study area is located in a public forest known as '*Pinar Grande*', which covers an area of 12,533 hectares. This forest is situated in the northern part of Sistema Iberico mountain range, in the region of "Pinares" (Soria). The study area is comprised of pure Scots pine (*Pinus sylvestris* L.) stands and small stands mixed with *Pinus pinaster* Ait., *Quercus pyrenaica* Wild. or *Fagus sylvatica* L. The most representative genera for biomass of epigeus macromycetes are: *Russula* (25.8 %), *Suillus* (21.1 %), *Boletus* (15.8 %), *Amanita* (8.5 %), *Pholiota* (5.8 %), *Cortinarius* (5.6 %) y *Tricholoma* (3.8 %) (Martínez Peña y Fernández, 1999). The most harvested species are *Boletus* gr. *edulis* and *Lactarius* gr. *deliciosus* (García Cid, 2002).

'Pinar Grande' has been managed since 1907, although nowadays it is mainly exploited for timber. Even though timber cutting and cattle can modify mushroom production, these do not disturb mushroom harvesting. However, mushroom harvesting is prohibited during the hunting season. Mushroom harvesting is not considered with sufficient detail in Pinar Grande management plans, despite its social and economic importance. In fact, mushroom harvesting could represent 6% of the value of timber, which collects income of €9 per hectare, even without taking into account the recreational value generated by mushroom harvesting (Martínez Peña, 2003). Other management alternatives show that the net present value generated by mushroom harvesting could be 40 % of the value obtained by timber cutting (Aldea, 2009).

Currently, the landowner of "Pinar Grande" does not obtain any income from mushroom harvesting and neither is it included in the regulated areas with harvesting licences, however this may change in future.

Methods

The travel cost model (TCM) of estimating the demand function has been applied to a wide range of recreational activities including hunting, fishing and forest recreation (Ward and Beal, 2000). The TCM is the approach selected to estimate the consumer surplus associated to recreational harvesting of edible wild mushrooms in '*Pinar Grande'*. Firstly, it is one of the most popular valuation techniques in measuring the value of a non-market resource (Inhyuck, 2007). Secondly, its application is cheaper than other methods, in particular contingent valuation methods and this reason is particularly important in situations such as this one which do not have financial backing.

This method has been developed from a suggestion made by Hotelling (1947) in a publication on the economist recreation in US national parks by the National Park Service. Hotelling suggested using the travel cost incurred by an individual when visiting a recreation site as an implicit price for the services of that site. Exploiting the empirical relationship between increased travel distances and associated declining visitation rates would permit one to estimate the demand relationship. In this way, the Marshallian demand curve for the recreation service can be estimated and appropriate consumer surplus measures calculated and thus provide a basis for comparing them with the cost of their supply.

Two major variants of the TCM are the zonal travel cost method (ZTCM) and the individual travel cost method (ITCM). A general reduced-form demand function relates visitation rates (VI) to travel cost (TC) and other relevant variables (X_i) and can be specified as:

$$VI_i = \alpha + \beta_1 TC_i + \beta_2 X_{2i} + \beta_3 X_{3i} + \cdots + \varepsilon_i \qquad [1]$$

Where α is the intercept, the β'_s are the regression parameters and ε_i is the error term indicating each zone or individual (Perman *et al*, 2004).

In the ZTCM, the area surrounding the recreation site is divided into various zones. Each zone has an average travel cost according to its distance from the site (Garrod and Willis, 1991). The visitation rate per zone, in a given time period, can be estimated using the average travel cost. Several authors have applied this version to estimate the demand relationship (English and Bowker, 1996; Bateman *et al.,* 1999; Bennear, 2005; Inhyuck, 2007). Various Spanish authors have also written on this subject (Campos and Riera, 1996; Martínez Peña, 2003; Riera y Farreras; 2004).

However, this approach has two important limitations (Ward and Bell, 2000). Firstly, there is the difficulty in accounting for the effects of travel time on individuals, since there is a high correlation between travel cost and travel time when individual experiences are averaged to estimate zonal values. In order to overcome multicollinearity in the regression analysis, travel time must be omitted. Secondly, the aggregation and averaging process required to estimate zonal values make certain demand determinants, particularly the socioeconomic variables, statistically non-significant. In effect, there is a loss of information efficiency.

The ITCM on the other hand, uses survey data from individual visitors to link the demand of natural resources to its determinants. These include how far the visitor must travel to get to the site, the amount of time spent travelling, travel and on-site expenses, their income and other socioeconomic characteristics, etc. Therefore, this method allows the amount of visits purchased at different prices to be calculated. The two advantages to the ITCM are that it follows conventional methods used by economists to estimate economics values based on market prices and also relies on what people actually do rather on what people say they would do in hypothetical situations (Bell and Leeworthy, 1990). Due to these reasons and to the weak theoretical foundation of the behavioural patterns in the aggregate demand models, this version is preferred over the ZTCM (Bhat *et al.*, 1998; Buchli *et al.*, 2003; Nillesen *et al.* 2005, etc. and Pérez y Pérez *et al.*, 1998; Riera, 2000; García and Colina; 2004, etc. in Spain), but in any case, economic theory shows individual models to be superior to zonal models (Fletcher *et al.*, 1990).

In this sense, empirical studies provide mixed results. For example, the ZTCM is considered more appropriate to estimate consumer surplus when visits are uniformly distributed and ITCM is more suitable for the case for multiple-destination due to the difficulty of obtaining the site-specific travel cost estimates (Cook, 2000). Given the availability of data and simplicity of application, the zonal approach has been used in this study. This methodology uses relatively straightforward demand models that, given certain research objectives, can indeed perform as well as individuals models (Hellerstein, 1995). We believe that this approach is suitable because the visits are uniformly distributed among Spanish provinces and recreational harvesting is the only reason to visit Pinar Grande in the autumn season (see data).

However, there are a number of problems that may arise in the implementation of the TCM. Two of them are briefly discussed here. The first is the choice of functional form used in the estimation of the demand curve. The economic theory of constrained optimisation with weak complementarity does not imply any particular functional form for the trip generating equation. Given no *a priori* guidance, the functional form is decided according to which fits the data better. This decision has important implications for the results obtained and affects both the expected value and variance of consumer surplus estimates (Ziemer *et al*., 1980; Hanley, 1989; Adamowicz *et al*., 1989; Hellerstein, 1991; Ozuna *et al*., 1993).

Three functional forms were used to estimate the econometric model of visitor demand; linear, semilog, and exponential specification functions. Linear models are the most commonly used to estimate using ordinary least square (OLS) regression. None of the variables need to be transformed, thus minimising potential coding errors. They are also easy to interpret for policy makers investigating visitor rates. However, linear models have been less popular during the last 20 years of published research in TCMs because the goodness of fit is worse than nonlinear forms (Ward and Bell, 2000). This is particularly the case where there are few visits at very high prices and many visits at near-zero prices. In our case, linear function had the least adjusted R^2 compared to the other two models so we rejected this approximation. Semi-log models, where the dependent variable is transformed by taking the natural logarithm, are commonly used in literature such as Ziemer *et al*. (1980), Vaughan *et al*. (1982), Strong (1983) or Willis and Garrod (1991). This specification shows the best adjusted R^2 , however, the test for the present of heteroscedasticity rejects the null hypotheses of homocedasticity, which would bias the estimates of parameters variance and lead to incorrect statistical conclusions, and therefore, we also rejected this specification. The third specification presents the second best adjusted R^2 after the semi logarithmic model and thus the exponential specification for the Clawson and Knetsch model was selected.

The second widely discussed aspect of TCM is the specification of the monetary price of recreation trip. There are four kinds of travel cost that could be used in a TCM study: petrol cost; full car running cost; out-of-pocket cost; and travel time cost, as well as the added decision for the investigator in determining which the part of the total travel cost to consider when a person or a family visits several sites during the trip.

In order to minimize the effect of the monetary travel cost specification on the estimated welfare measures only petrol cost is taken as an approximation of the travel cost. Although not common practice, it is a more cautious measure. If the obtained measures are to be used as a guide in making forest policy decisions, these values would need to be the most cautious possible and cannot be seen to be influenced by the decisions taken by the investigator (Randall, 1994).

The following demand function was estimated for all years between 1997 and 2005 as follows:

$$Ln(VI_i) = \alpha + \beta_1 * {}^{1}\!/_{TC_i} + \beta_2 * GDPpc_i + \beta_3 * MS_i + \varepsilon_i \quad [2]$$

Where i-zones are Spanish provinces, equivalent to two digits statistical division of National Statistics Institute (Spanish Statistical Office). VI_i are the visitation rates of area i, defined as visitation per 1,000 inhabitants and were calculated using the following formula:

$$VI_i = \frac{V_i * 1000}{P_i} \quad [3]$$

TC_i are the vehicular travel costs based on average running petrol costs per kilometre between the capital of area i and the study site. It is expected that this variable would be negative, in the sense showed by the economic theory. $GDPpc_i$ are the per capital gross domestic product of the i areas, used to display the effect of level income on the demand function. Therefore, the expected sign of this variable would be positive in the sense shown by the economic theory. MS_i are the number of mycological societies in the i areas and could be used to show the preferences of the inhabitants of these areas in the recreational harvesting of edible wild mushrooms. The expected sign of this variable would be positive in the sense shown by the economic theory.

The initial models included the migration rates of i zones (MR_i), defined as the percentage of persons of i areas who were born in Soria. This variable could shows the importance of these people born in Soria who return to the study area every year in picking season as they did when they lived in Soria. However, this variable is correlated with the distance and, therefore, with the cost of the trip, generating multicollinearity problems. Therefore, this variable was eliminated from the demand equation. The explanatory reasons for this behaviour are that the population emigrates to nearest provinces.

The estimated travel costs regression coefficients can be used to determine the value of recreational harvesting of edible wild mushrooms in '*Pinar Grande'* in terms of consumer surplus in any year. Using an evaluation technique, often known as the Hotelling-Clawson approach, the travel cost coefficient is used as a measure of sensitivity of participants to added cost, such as a harvest fee (Clawson and Knetsch, 1966). If *hf* is the added cost, equation [2] becomes:

$$\frac{\hat{V}_i * 1000}{P_i} = e^{\hat{\alpha} + \frac{\hat{\beta}_1}{(TC+hf)_i} + \varepsilon_i} \quad [4]$$

Where $\hat{V}_i$ is the estimated numbers of annual trips from area *i* to *Pinar Grande* and $\hat{\alpha}$ and $\hat{\beta}_1$ the estimated regression parameters. We can refer to the relationship in equation [4] as the Marshallian or *uncompensated* demand curve which includes the income effect of a price change. Integrating this equation for each year, results in an estimate of the annual Marshallian consumer surplus (MCS) in the absence of a harvest fee[1]. The maximum willingness to pay every year for the area under the travel cost derived demand curve (Anex, 1995) is calculated. This estimation could be an accurate approximation of the individual recreational harvester's welfare under the assumption of a free access situation. Equation [4] can be integrated as follows:

$$MCS = \int_{atc}^{mtc} e^{\hat{\alpha}+\frac{\hat{\beta}_1}{TC}} dTC \qquad [5]$$

Where *atc* is the weighted average actual travel cost in every year and *mtc* is the cost at which no trips are demanded, also known as the chock price. Given the characteristics of the estimated demand function, the chock price would be infinite. The calculation of the Marshallian consumer surplus would not be possible using an infinite price chock. In order to solve this problem travel cost was replaced by the maximum cost possible to access the zone from within Spain. This decision has been justified by it being improbable that trips are demanded from a greater distance.

The mathematical solution of the integration process returns the following formula (see appendix) to calculate the MCS of recreational harvesting of edible wild mushrooms in '*Pinar Grande'*:

$$MCS = e^{\hat{\alpha}}\left\{(mtc - atc) + \hat{\beta}_1 \ln\frac{mtc}{atc} + \sum_{n=0}^{\infty}\left[\frac{\hat{\beta}_1^{\,n+2}}{(n+2)*(n+1)} * \left(\frac{1}{atc^{n+1}} - \frac{1}{mtc^{n+1}}\right)\right]\right\} \qquad [6]$$

Finally, we tested the explanation factors of the Marshallian consumer surplus in every year adjusting the following equation using OLS regression:

$$Ln(MCS_t) = \alpha' + \beta'_1 * BEFP_t + \beta'_2 * BEFP_{t-1} + \beta'_3 * CP_t + \varepsilon_i \qquad [7]$$

Where t are the years between 1997 and 2005. MCSt are the estimated Marshallian consumer surplus in every year, and $BEFP_t$ are the fit production in kilogrammes per hectare of the most important species harvested in *'Pinar Grande'* (*Boletus edulis*) in every year. The expected sign of this variable would be positive, in the sense of bigger harvests: greater satisfaction. $BEFP_{t-1}$ are the retarded fit production in kilogrammes per hectare of the most important species harvested in *'Pinar Grande'* (*Boletus edulis*) in every year. The expected sign of this variable would be positive because harvesters could travel to the study area expecting find it in the same condition as the previous year. CP_t are the cost of petrol in every year. The expected sign of this variable is indeterminate and depend on demand elasticity-price of equation 2. If petrol cost was to change, it could impact on the number of visits, the sign would be negative and vice versa.

The initial model included the number of mycological societies in Spain in every year (MS_t). However, this variable was correlated with the cost of petrol (CP_t), generating multicollinearity problems[2]. This variable was eliminated of the analysis.

Data

Aggregation (i areas) was selected on a provincial level for two reasons. Firstly, the sample plates only were available in this disaggregation level and, therefore, it was the only way to get the dependent variable V_i. Secondly, in Spain there is no reliable statistical information to lower aggregations, except on a municipal level, but disaggregation occurs to such an extent that it does not respond to the focus of the study. Higher aggregation was possible at one digit statistical division of National Statistics Institute (Spanish Statistical Office) equivalent to Autonomous Communities level, but this aggregation was rejected due to the loss of information efficiency. Spain has 52 provinces, the autonomous cities of Ceuta and Melilla included. Five of them were eliminated because is not possible travel to the study site by car.

The total visitation of recreational harvesting of edible wild mushrooms per zone data (V_i) were collected by the Department of Forestry Investigation, Valonsadero (a department dependent on the regional government), in the study area from 1997 to 2005. This data was obtained from weekly surveys on forest tracks accessible to vehicles randomly selected in the '*Pinar Grande'* forest. The surveys counted the number of parked vehicles belonging to harvesters and their

[1] The hicksian compensating variation and equivalent variation welfare measures are the theoretically correct measures of the value of the benefits, even though Willig (1976) showed that consumer surplus is an acceptable approximation.

[2] These variables have a growing trend during the study period.

province of origin according to the number plates. The sampling was always performed following the same pattern, starting and finishing at the same time of day, covering the 16 forest tracks (29.5km of the total 96.5km of forest tracks accessible in the forest). The sampling was carried out on a weekly basis throughout the autumn every year from 1997 through to 2005, totalling 126 samples. Each sample allowed for an estimation of the average number of harvesters per kilometre of forest path per day from each province of origin. Multiplying this figure by the total 96.5km (of forest tracks), the total number of harvesters per day who had travelled from each different place was calculated for the whole of '*Pinar Grande'* (Ortega-Martínez, 2005).

Although the mushroom harvesting takes place in spring and autumn, only autumn was considered for the inventory of production and vehicles as this season is the most important in terms of production and harvester activity. In any case, the sample was considered sufficiently representative because it takes into account 30 % of the total forest tracks in the areas with poor accessibility and lower quality of mushroom production. Moreover, when the number plates of the vehicles were insufficient to ascertain the origin of vehicle, the distinguishing dealership sticker was used.

All of the vehicles belonged to mushroom harvesters, because according to vehicle surveys for this area during the year, vehicles are only observed when harvesting of edible wild mushroom occurs in autumn.

Commercial harvesters were eliminated from the analysis of annual samples using data from the Department of Forestry Investigation, Valonsadero. The percentage of commercial harvesters was extracted from the total number of harvesters in terms of their province of origin.

The vehicular travel costs (TC_i) were calculated for a range of different types of cars under the assumption that the type of vehicle a person owns and the price of the petrol does not depend on the zone of origin and that costs per kilometre are the same across all zones. For each year, the weighted-average running cost in current euros was calculated using data from the Minister of Industry, Tourism and Trade on distances and prices of petrol (MITT, 1997-2005).

The population per zone i (P_i) and per capita domestic gross product of i zones ($GDPpc_i$) were collected of the National Statistics Institute (NSI, 1997-2005).

The number of mycological societies in i zones (MS_i) were collected from several sources like mycological publications, association web sites, regional governments requests, etc.

Finally, the fit productions in kilogrammes per hectare of the most important species harvested in 'Pinar Grande' (Boletus edulis), $BEFP_t$ and $BEFP_{t-1}$, were collected in the study area during the period 1997-2005 (Martínez Peña, 2009).

Results

The results of the ordinary least squares estimation of the demand models described by equation [2] for all years are presented in Table 1 and 2.

The models were evaluated using several criteria, including explanatory power (adjusted R^2) and significance (F-value). In the first case, the explanatory power is very high for all years with adjusted R^2 between the values of 0.623 (2005) and 0.823 ((2001). In the second case, F-ratio value indicated that all models were significant overall at the 1% level, except for 2005, significant at the 5% level.

With respect to the price or travel cost coefficients estimates for each of the nine annual models, were consistent with demand theory, in that the quantity of visitors per 1000 inhabitants in the area was inversely related to price or travel cost. Intercept and travel cost coefficients are significant at the 1% level for all years, except 2005 travel cost coefficient that is significant at the 5% level. In relation to other coefficients, the major limitation of ZTCMs is the loss of data variation due to zonal averaging that results in insignificant social and demographic variables (Poor and Smith, 2004), as in this case. For example, provincial per-capita income only was significant in three years, one at 1% level (2002), one at 5% level (1998) and one at 10% level (2001). On the other hand, the sign of these coefficients is positive and is the expected according to consumer behaviour (except in 2005). However, the number of mycological societies was insignificant for all years and it sign is negative which goes expectations.

The models were tested for heterodedasticity because travel cost models with unequal populations often lack homocedasticity, which is caused by the difference in visitation rates from zones with larger populations being greater than in zones with smaller populations (Bowes and Loomis, 1980; Vaughan *et al*., 1982). This problem is also common when there are variations in visitation rates between zones (Christensen and Price, 1982). The correlation between dependent variable predicted adjusted values and standardised residuals regression, using Pearson's correlation coefficient,

Table 1. Ordinary least squares estimates for recreational harvesting of edible wild mushrooms in *'Pinar Grande'* (Soria-Spain): summary models and Marshallian consumer surplus

YEAR	R	R^2	Adjusted R^2	F	Sig (99%)	Durbin-Watson	Pearson´s correlation coefficient	Kolmogorov Smirnov (Z)	atc (weighted)	mtc	MCS
1997	0.850	0.722	0.667	13.013	YES	1.830	-0.048	0.661	27.29	356.82	**18.84**
1998	0.901	0.812	0.775	21.612	YES	2.256	-0.075	0.629	19.88	356.82	**27.36**
1999	0.853	0.728	0.680	15.15	YES	1.665	-0.058	0.348	27.30	356.82	**21.27**
2000	0.926	0.857	0.803	15.981	YES	1.981	-0.096	0.698	25.64	356.82	**18.11**
2001	0.923	0.853	0.823	28.979	YES	1.679	-0.077	0.653	25.39	356.82	**28.81**
2002	0.898	0.806	0.773	24.856	YES	2.270	0.434	0.406	25.32	356.82	**22.53**
2003	0.850	0.722	0.673	14.751	YES	2.305	-0.076	0.574	24.50	356.82	**28.07**
2004	0.918	0.842	0.809	24.951	YES	1.953	-0.064	0.52	26.20	356.82	**15.42**
2005	0.836	0.698	0.623	9.254	YES (*)	2.010	-0.244	0.407	18.73	356.82	**12.23**

(*) Significant at the 95% significance level. Source: own elaboration.

was insignificant at the 95% significance level. Heterodedasticity is not, therefore, considered to be a problem for this analysis.

The models were also tested too for autocorrelation, using the Durbin-Watson test, and residuals normality absence[3], using Kolmogorov-Smirnov test with the standardised residuals sample. In all years the applied test rejected the presence of these problems, and so the models are believed to be valid for prediction making and the Marshallian consumer surplus is calculated in terms expressed in formula number 6.

The results of the integration process, between actual and maximum travel cost (*atc* and *mtc*), for all years are presented in final columns of Table 1. The range of the consumer surplus varies between the 12.23€ per car in 2005 (minimum MCS) to 28.81€ per car in 2001 (maximum MCS) where the average of the period reaches a value of 21.40€.

According to face to face surveys conducted in the autumn seasons in Pinar Grande (García Cid, 2002), the average number of people per local car was 2.02 (1.8 adults and 0.22 children) and 2.57 per car coming from outside of Soria (2.29 adults and 0.28 children). The weighted average per car in the period 1997-2005 is 2.28[4] (2.03 adults and 0.25 children). The consumer surplus per harvester varies between

Table 2. Ordinary least squares estimates for recreational harvesting of edible wild mushrooms in *'Pinar Grande'* (Soria-Spain): demand parameters

YEAR	A				β_1				β_2				β_3			
	Value	Standard error	t-value	Sig (99%)	Value	Standard error	t-value	Sig (99%)	Value	Standard error	t-value	Sig (99%)	Value	Standard error	t-value	Sig (99%)
1997	-3.623	1.234	-2.937	YES	34.692	5.597	6.198	YES	0.045	0.086	0.520	NO	-0.08	0.088	-0.86	NO
1998	-6.084	1.344	-4.528	YES	48.803	6.591	7.405	YES	0.204	0.095	2.159	YES (*)	0.06	0.116	0.48	NO
1999	-4.276	1.130	-3.783	YES	46.242	7.112	6.502	YES	0.078	0.077	1.017	NO	-0.01	0.101	-0.08	NO
2000	-4.868	1.331	-3.658	YES	47.509	7.296	6.511	YES	0.087	0.086	1.001	NO	0.06	0.126	0.51	NO
2001	-5.244	1.398	-3.750	YES	54.197	5.935	9.132	YES	0.134	0.073	1.849	YES (**)	-0.04	0.073	-0.59	NO
2002	-5.972	1.148	-5.201	YES	52.924	7.011	7.549	YES	0.173	0.066	2.632	YES	-0.07	0.088	-0.78	NO
2003	-4.481	1.366	-3.281	YES	50.065	7.947	6.300	YES	0.084	0.075	1.122	NO	0.00	0.094	-0.03	NO
2004	-5.179	1.202	-4.309	YES	48.975	5.974	8.198	YES	0.072	0.061	1.179	NO	0.08	0.060	1.34	NO
2005	-3.704	0.856	-4.327	YES	38.799	12.754	3.042		-0.07	0.285	-0.26	NO	-0.42	0.410	-1.01	NO

(*) Significant at the 95% significance level. (**) Significant at the 90% significance level. Source: own elaboration.

[3] This aspect could be a problem with small samples like in this case.

[4] The data are coherent with Schlosser and Blatner (1992). These authors found an average of 2.2 harvesters per car in Oregon National Parks.

the 6.05€ per adult person in 2005 to 14.19€ in 2001, where the average of the period reaches a value of 10.49€.

Finally, the results of the ordinary least squares estimation of the explanations factors of the Marshallian consumer surplus model, described by equation number 7, are presented in Table 3.

In terms of goodness-of-fit statistics for all tested specifications of the model, the exponential model offered the best adjustment with a value of the adjusted R^2 of 0.538. The F ratio test indicates that the results are significant at the 10% level. In terms of estimated coefficients, only fit production in kilogrammes per hectare of *Boletus edulis* was significant (5% level) and positive and, therefore, consistent with the expected. Other variables, like retarded fit production and cost of petrol was non-significant. These variables therefore do not influence the harvesters' well-being in any significant way. In this case, it is only important if the visitor finds edible wild mushrooms. In addition, a well-informed harvester only travels if a certain quantity of this forest production is expected to be collected, and their well-being will increase in an exponential form with their harvest. Therefore, recreational harvesters visit more to look for edible wild mushrooms in propitious season because the fundamental variable to travel is find edible wild mushrooms. That is to say, there is a negative relationship between the wellbeing of recreational harvesters and the value of the edible wild mushrooms they picked compared to their price in local markets[5], since in high season prices tend to drop. This behaviour differs from commercial harvesters who prefer to collect at high prices although the quantity would be reduced, increasing their income wherever possible[6].

Conclusions and discussion

The knowledge of the demand function is fundamental for the management of this resource. Its estimation allows us to calculate the maximum willingness to pay, in the form of Marshallian consumer surplus, through a hypothetical regulation of edible wild mushrooms picking, the access permits that increase travel costs. In the case of '*Pinar Grande*' the average of the period under study reaches a value of 21.41€ per car (10.49€ per adult person) and varies between 12.59€ per car (6.05€ per person) in 1995 and 28.73€ per car (14.91€ per person) in 2001. These values depend on the seasonal variations in production of edible wild mushrooms in this zone. In particular, the season, considered in terms of edible wild mushroom availability in the forest, accounts for approximately 54% of the Marshallian consumer surplus of recreational harvesters.

Several authors find similar values applying this methodology to other recreational activities in natural spaces in Spain during the study period. For example, using ZTCM, Campos and Riera (1996) estimate the MCS in 8.41€ per visitor to Monfragüe Natural Park and Riera y Farreras (2004) in 37.06€ per car in tourism in the Basque Country[7]. Using ITCM, Pérez y Pérez et al (1996), Saz (1996) and García and Colina (2004) calculate these values in 14.21€, 15.24€ and 15.55€ per visitor respectively to several natural parks in Spain (Posets Maladeta, L´Álbuera and Somiedo)

Table 3. Ordinary least squares estimates for Marshallian consumer surplus of recreational harvesting of edible wild mushrooms in *'Pinar Grande'* (Soria, Spain): summary model and parameters

Summary model	Value	Parameters	Value	Standard error	t-value	Sig (95%)
R	0.843	α'	3.207	0.633	5.064	YES
R2	0.711	β_1'	0.009	0.003	2.643	YES
Adjusted R2	0.538	β_2'	0.001	0.003	0.238	NO
F	4.113	β_3'	-0.362	0.764	-0.827	NO
Sig (95%)	YES (*)					
Durbin-Watson	2.748					

(*) Significant at the 90% significance level. Source: own elaboration.

[5] In favourable seasons there is a negative relationship between the production of edible wild mushrooms and their price, in the sense expressed by the economic theory.

[6] Its depends on the price-elasticity of edible wild mushrooms demand in the markets

[7] These authors use out-of-pocket cost like independent variable.

The comparison is paradoxical with the results of edible wild mushrooms TCM studies in Spain. For example, Mártinez de Aragón (2005), using ITCM estimates in 38.22€ for each person who harvests in Solsones area (Catalonia). The explanation could be the use of out-of-pocket cost as an independent variable instead petrol cost as in our case. Martínez Peña (2003) finds bigger differences in the same study area (Pinar Grande) with 188€ per car. The source of divergence could be due to the use of full-car-running cost, the absence of local harvesters in the sample or econometrics aspects during the process of estimation of demand function.

We can also compare the range of estimated Marshallian consumer surplus of recreational harvesters (6.05-14.91 euros) with the daily recreational licence cost in regulated areas (5 euros). This demonstrates that there is an important difference which could be incorporated into tax management and the regulation of the resource via harvest fees. Another matter is the social response to an increase in the cost of licences, which would need investigating beforehand.

In conclusion, if the consumer surplus depends on edible wild mushroom production, so too would the hypothetical harvest fee. The found exponential relation could serve as an aid to managers of the resource when deciding upon the rate. Thus, for low edible wild mushrooms productions in the forest, lower consumer surpluses for harvesters and vice versa. For low edible wild mushroom production, the fees do not have to be very high but could grow substantially according to improvements in the mushroom season.

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Appendix

$$MCS = \int_{atc}^{mtc} e^{\hat{\alpha}+\frac{\hat{\beta}_1}{TC}} dTC = \int_{atc}^{mtc} e^{\hat{\alpha}} e^{\frac{\hat{\beta}_1}{TC}} dTC = e^{\hat{\alpha}} \int_{atc}^{mtc} e^{\frac{\hat{\beta}_1}{TC}} dTC$$

$$Variablechange \rightarrow \frac{1}{TC} = t \Rightarrow dTC = -\frac{-dt}{t^2}, t_1 = \frac{1}{mtc}, t_0 = \frac{1}{atc} \Rightarrow$$

$$MCS = e^{\hat{\alpha}} \int_{\frac{1}{atc}}^{\frac{1}{mtc}} e^{\hat{\beta}_1 t} (-dt/t^2) = -e^{\hat{\alpha}} \int_{\frac{1}{atc}}^{\frac{1}{mtc}} \frac{e^{\hat{\beta}_1 t}}{t^2} dt = e^{\hat{\alpha}} \int_{\frac{1}{mtc}}^{\frac{1}{atc}} \frac{e^{\hat{\beta}_1 t}}{t^2} dt = (I)$$

$$f(t) = e^{\hat{\beta}_1 t}; f'(t) = \hat{\beta}_1 e^{\hat{\beta}_1 t}; f''(t) = \hat{\beta}_1^2 e^{\hat{\beta}_1 t}; f'''(t) = \hat{\beta}_1^3 e^{\hat{\beta}_1 t}; \ldots; f^{(n)}(t) = \hat{\beta}_1^n e^{\hat{\beta}_1 t}$$

$$f(0) = 1; f'(0) = \hat{\beta}_1; f''(0) = \hat{\beta}_1^2; f'''(0) = \hat{\beta}_1^2; \ldots; f^{(n)}(0) = \hat{\beta}_1^n$$

$$f(t) = e^{\hat{\beta}_1 t} = 1 + \frac{\hat{\beta}_1}{1!} * t + \frac{\hat{\beta}_1^2}{2!} * t^2 + \ldots = \sum_{n=0}^{\infty} \frac{\hat{\beta}_1^n}{n!} * t^n \; (folowingMcLaurin)$$

So we can integrate (l) in the following way:

$$g(t) = \frac{e^{\hat{\beta}_1 t}}{t^2} = \sum_{n=0}^{\infty} \frac{\hat{\beta}_1^n}{n!} * t^{n-2}$$

If G(t) is the primitive of g(t) then,

$$G(t) = -\frac{1}{t} + \hat{\beta}_1 \ln t + \frac{\hat{\beta}_1^2}{2!} * t + \frac{\hat{\beta}_1^3}{3!} * \frac{t^2}{2} + \ldots = -\frac{1}{t} + \hat{\beta}_1 \ln t + \sum_{n=0}^{\infty} \frac{\hat{\beta}_1^{n+2}}{(n+2)!} * \frac{t^{n+1}}{n+1}$$

So, following Barrow:

$$(I) = e^{\hat{\alpha}} \int_{\frac{1}{mtc}}^{\frac{1}{atc}} g(t)dt = e^{\hat{\alpha}} [G(t)]_{\frac{1}{mtc}}^{\frac{1}{atc}} = e^{\hat{\alpha}} \left[G\left(\frac{1}{atc}\right) - G\left(\frac{1}{mtc}\right) \right] =$$

$$e^{\hat{\alpha}} \begin{bmatrix} \left(-atc + \hat{\beta}_1 \ln \frac{1}{atc} + \left(\frac{\hat{\beta}_1^2}{2!}\right) * \left(\frac{1}{atc}\right) + \left(\frac{\hat{\beta}_1^3}{3! * 2}\right) * \left(\frac{1}{atc^2}\right) + \ldots \right) - \\ (-mtc) + \hat{\beta}_1 \ln \frac{1}{mtc} + \left(\frac{\hat{\beta}_1^2}{2!}\right) * \left(\frac{1}{mtc}\right) + \left(\frac{\hat{\beta}_1^3}{3! * 2}\right) * \left(\frac{1}{mtc^2}\right) + \ldots \end{bmatrix} =$$

$$e^{\hat{\alpha}} \left\{ (mtc - atc) + \hat{\beta}_1 \ln \frac{mtc}{atc} + \left(\frac{\hat{\beta}_1^2}{2!}\right) * \left[\left(\frac{1}{atc}\right) - \left(\frac{1}{mtc}\right) \right] + \left(\frac{\hat{\beta}_1^3}{3! * 2}\right) * \left[\left(\frac{1}{atc^2}\right) - \left(\frac{1}{mtc^2}\right) \right] + \ldots \right\}$$

Then

$$MCS = e^{\hat{\alpha}} \left\{ (mtc - atc) + \hat{\beta}_1 \ln \frac{mtc}{atc} + \sum_{n=0}^{\infty} \left[\frac{\hat{\beta}_1^{n+2}}{(n+2) * (n+1)} * \left(\frac{1}{atc^{n+1}} - \frac{1}{mtc^{n+1}} \right) \right] \right\}$$