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Do outdoor recreation participants place their lands in conservation easements?

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Abstract

It has been posited that participation in outdoor recreation activities increases awareness of environmental issues and support for environmental conservation. Studies have shown that different outdoor recreationists may have different environmental orientations. For example, because of their utility orientation toward land, consumptive recreationists may be less likely than non-consumptive recreationists to protect their land from development. Hence, using a United States household survey, this paper examines whether people participating in consumptive outdoor recreation activities differ from those who participate in non-consumptive recreation in their willingness to place their lands into conservation easements. Results indicate people who participate in land-based consumptive recreation are less likely to place their lands in conservation easements than people who participate in land-based non-consumptive recreation.

Keywords

Conservation easement, environmental concerns or awareness, natural resources, open space, outdoor recreation participation

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Introduction

It has been posited that participation in outdoor recreation activities increases awareness of environmental issues, enhances pro-environmental attitudes, and increases likelihood of supporting environmental conservation (Tarrant and Green 1999; Theodori et al. 1998). However, empirical findings concerning this issue are mixed and inconclusive. While the relationship between outdoor recreation participation and environmental attitudes or behavior has been shown to exist in regard to local environmental issues, such as concern for local forests or other natural resources, evidence of this relationship weakens when the environmental issues are broad scale, such as environmental pollution (Porter and Bright 2003).

Outdoor recreationists can interact with natural settings in a variety of ways as they engage in recreation activities. For example, bird watchers may seek out quiet, undisturbed places, while off-highway riders may seek the opposite. It is thus reasonable to expect some differences among recreationists in terms of their interactions with and attitudes toward natural settings. Because of goal differences, one might expect participants in consumptive recreation (e.g., hunting or fishing) to differ from non-consumptive recreation participants (e.g., wildlife watchers or hikers) in regards to their environmental orientations (Dunlap and Heffernan 1975; Jackson 1986). However, research on environmental behaviors of outdoor recreationists has not adequately explored whether participants who choose different recreation activities have different interests and ways of engaging in environmental protective activities. An example of such an activity is for a person to place their land into a conservation easement. A conservation easement is a voluntary and legal agreement between a landowner and an easement holder to protect its conservation values. Participating into an easement agreement may also give financial benefits to the landowners (e.g., federal tax benefits of qualified donations in the United States).

Some studies have shown that consumptive recreationists are more utility oriented (Dunlap and Heffernan 1975; Theodori et al. 1998), and, hence, place less emphasis on the public good aspect of land conservation easements. To shed more light on the relationship between outdoor recreation participation and environmental orientations, this study analyzed data from a United States household survey in which respondents were asked about their outdoor recreation activities and whether they own any category of land (e.g., agricultural land, forestland, wetland, or other open space) and, if so, whether they have placed their lands under a conservation easement.

Examining the relationship between recreation participation and willingness to place land into a conservation easement is relevant for various reasons. Availability of places for outdoor recreation, such as public parks and open space has a significant role in helping people remain physically active and healthy (Physical Activity Council 2013). However, because of urbanization and population growth, demand for places for outdoor recreation is increasing, while the supply is relatively restricted in scope. One solution to this demand-supply imbalance is to increase open space through conservation easements on private land. In this regard, findings of this study could be useful in efforts to expand land area under such easements and also to help increase open space for outdoor recreation.

Outdoor recreation participation and environmental behaviors

Participation in outdoor recreation seems to be associated with people's pro-environmental attitudes. For instance, literature provides three arguments for this association. First, participation in outdoor recreation increases direct experiences with the natural environment and can also increase participants' attachment to areas where they recreate. Increased contact and attachment may help people become more aware of the values of nature, of associated environmental issues, and provide them with greater inspiration to conserve the environment (Porter and Bright 2003; Thapa and Graefe 2003). Direct contact may also help shape people's environmental attitudes or behaviors because personal experience often leads to greater understanding and appreciation of natural resources (Tarrant and Green 1999). Second, outdoor recreation participation can offer learning opportunities that are likely to influence recreationists' environmental attitudes or behaviors (Thapa 2000). Examples of such opportunities may include interpretative messages and information on kiosks in areas where people recreate. This information can help recreationists become more familiar with local environmental issues. Finally, outdoor recreation participation can be thought of as a pathway to and a marker of sub-cultural membership. For instance, outdoor recreationists can be recruited for involvement with conservation organizations through membership and other forms of support (Teisl and O'Brien 2003).

It has been argued that choice of and participation in different recreation activities are influenced by individuals' environmental values or attitudes (Bjerke et al. 2006; Jackson 1986). People participating in different types of outdoor recreation may have different value orientations toward or concerning environmental conservation (Peterson et al. 2008; Theodori et al. 1998). One distinction between types of outdoor recreation is consumptive versus non-consumptive activities. Consumptive activities typically involve a mode of participation in which participants physically take something directly from the recreation setting. Consumptive activities are often seen as having a 'utilitarian' orientation. In contrast, non-consumptive activities are those in which enjoyment of the natural environment is often accomplished without removing anything (Dunlap and Heffernan 1975). However, depending on which consumptive or non-consumptive activities are being considered, both types of activities can alter by varying degrees the natural condition of the setting.

According to Vaske et al. (1982), there are two important goal oriented differences between participation in consumptive versus non-consumptive activities. First, consumptive activities are dominated by one clear, specific, and observable goal, which is, acquisition or harvesting of the natural product of interest. For instance, hunters seek to harvest game, and fishers want to catch fish. In contrast, the goals of non-consumptive recreationists are more general and less well-defined. Second, consumptive recreationists may have less control in achieving the defining goal of their activities than do non-consumptive recreationists. Backpackers or campers, for instance, may be motivated to experience nature, test their skills, experience solitude, and/or to be with friends. While these goals can be achieved throughout the entire experience, they do

not depend on acquiring a specific product, and are more easily substituted, if one goal is not satisfied. Some research has asserted that because consumptive recreationists extract resources from the environment, they have different environmental orientations than non-consumptive recreationists. This assertion has been examined and re-examined over decades, with mixed and inconclusive results.

Dunlap and Heffernan (1975) tested three hypotheses regarding outdoor recreation participation and environmental concern, which were: involvement in outdoor recreation is positively associated with environmental concern; involvement in non-consumptive outdoor recreation is more strongly associated with environmental concern than involvement in consumptive outdoor recreation; and the association between outdoor recreation involvement and protecting those aspects of the environment necessary for pursuing such activities is stronger than the association between outdoor recreation and other environmental issues, such as air and water pollution. However, Dunlap and Heffernan found weak support for their first hypothesis, modest support for their second hypothesis, and somewhat stronger support for their third hypothesis. In other words, the authors found non-consumptive recreationists expressed greater environmental concern than did consumptive recreationists. In subsequent studies, Pinhey and Grimes (1979) and Jackson (1986) also found support for Dunlap and Heffernan's hypotheses. In contrast, Geisler et al. (1977) and Van Liere and Noe (1981) found weak-to-no support for these hypotheses.

Because of these goal oriented differences, we *hypothesized* that consumptive recreationists have a different sensitivity to environmental issues, and, hence differ from non-consumptive recreationists in their support for and participation in conservation easement programs. Hence, building upon previous studies, we examined the hypothesis that consumptive recreationists are less likely to place their lands under easements, compared to their non-consumptive counterparts.

Determinants of conservation easements and pro-environmental attitudes or behaviors

Conservation easements are an important tool employed widely across the United States to protect ecological, historical, or scenic resources. Through this agreement, the landowners accept permanent restrictions on the way their property can be used. The easements provide landowners with a legal mean of protecting their properties' conservation values while retaining ownership, and being allowed certain complementary uses (Gustanski 2000). Easements may also yield financial benefits to landowners. For instance, the income tax benefits of qualified donations of lands or revenues from the sale of an easement have made the mechanism attractive for many landholders in the United States. The property protected may be any category of land, such as agricultural land, forestland, wetland, or natural open space. The easement agreement doesn't restrict landowners selling the lands or pass it onto heirs, but the property remains bound by the terms of the conservation easements.

Previous studies have analyzed factors affecting individuals' decisions to place their land in a conservation easement (e.g., Duke 2004, Johnston and Duke 2007; Lynch and Lovell 2003). These studies have found that area of landholding, distance from urban area, land value (opportunity costs of landholding), and agriculture returns to be important determinants of whether a piece of land is placed under an easement. Area of landholding has been shown to be positively associated with individuals' participation in conservation easements (Johnston and Duke 2007; Lynch and Lovell 2003). Individuals with more acreage may also donate some part of their lands for easements because of diminishing marginal utility of holding additional acreage. In considering purchasing of conservation rights, a land trust or local government unit may be attracted by a lower price per acre for large tracts (Lynch and Lovell 2003). Individuals with forests may also wish to participate in an easement agreement (e.g., forest easements) to protect their forestland from development.

Since undeveloped lands near a city, highway, or other developed areas have higher net returns from converting these lands through development, they are less likely to be placed under easements (Lynch and Lovell 2003). Similarly, lands with higher market value have greater opportunity costs to be considered before deciding whether or not to place them under easement (Cooper and Osborn 1998; Konyar and Osborn 1990). In contrast, higher returns from agricultural use increase the probability of placing lands under easements because the owner of a profitable farm might want to farm the land in the future and, thus, want to conserve it from development (Lynch and Lovell 2003). Besides economic values, some landholders may wish to preserve their lands due to non-consumptive values, such as a desire to preserve the land in a natural condition for one's heirs (Rilla and Sokolow 2000). Thus, years of land tenure and having a family member who may be interested in taking over stewardship of the land may increase the probability of participating in easements (Lynch and Lovell 2003).

Research on the relationship between outdoor recreation participation and placing land into a conservation easement is limited. However, some studies have examined the relationship between recreation participation and environmental attitudes or behaviors. Generally, it appears that participation in outdoor recreation is associated with pro-environmental attitudes. Hence, knowing a person's environmental attitudes may help understanding of how outdoor recreation participation may affect landowners' decisions to place their lands under conservation easements.

Individual socioeconomic and demographic characteristics, such as income, education, age, gender, and household size are also important determinants of environmental attitudes or behaviors (Gatersleben et al. 2002; Guerin et al. 2001). For instance, people with higher income tend to be more pro-environmental because they can bear the marginal increase in costs associated with supporting the environment (Straughan and Roberts 1999; Zimmer et al. 1994). Likewise, people with higher education better understand the consequences of environmental degradations and the need for conservation. Thus, people with higher education are more likely to be pro-environmentalists (Diamantopoulos et al. 2003).

Additionally, younger people are more likely to be sensitive to environmental issues and also be pro-environmental because they have grown up in a time in which environmental concerns have been a salient issue at some level (Straughan and Roberts 1999; Zimmer et al. 1994). Similarly, females are argued to be more pro-environmentalists than males due to their social development and gender role differences. For instance, females (more so than males) carefully consider the impacts of their actions on others (Stern et al. 1993; Straughan and Roberts 1999). Studies also posit that ethnic minorities are more concerned with environmental issues and are pro-environmentalists because they can be disproportionately victimized by environmental hazards (Brown 1995; Bullard 2000).

In summary, reviewed literature indicates that participation in outdoor recreation activities is associated with pro-environmental attitudes and that pro-environmental attitudes may motivate people to participate in environmental conservation programs, such as land conservation easements. Thus, this study aims to explore whether there is an extension of this relationship in that participation in different types of outdoor recreation is associated with participation in conservation easement programs.

Methods

Econometric model

We modeled the probability of placing lands under conservation easements (*CEs*) as a function of type of outdoor recreation activity participation (***R***). We identified two groups based on the types of recreation they participated in (i.e., consumptive or non-consumptive activities). Literature on recreation participation has shown some key differences in the determinants of demand for land-based consumptive activities, like hunting, and water-based activities, such as fishing (Floyd and Lee 2002). Accordingly, recreationists were further grouped based on whether their activities were land-based or water-based. A land-based consumptive recreation dummy was created with a value one to reflect participation in consumptive activities that were land-based, and zero otherwise. Similarly, a water-based consumptive recreation dummy was created and set equal to one if a respondent participated in consumptive activities that were water-based, and zero otherwise. Since both individual and community characteristics are important determinants of conservation easement participation and of environmental orientation, this study considered individual socioeconomic and demographic characteristics (***I***) to include gender (male/female), income, education, race (ethnic minorities), age, parcel of land owned (proxy for area of landholding), area of forest owned, years of land tenure, and family size; and community characteristics (***C***) to include gross returns per acre (proxy for land productivity), median housing value, residency location (urban/rural), and distance from major cities. Since difference in culture, topography, and land availability across the United States may lead to variation in outdoor recreation participation (Ghimire et al. 2014) and also variation in decisions

regarding placing lands into conservation easements, we controlled for geographic regions at a broad spatial level, using geographic region dummies (please visit http://www.fs.fed.us/research/rpa/regions.php to know more about the geographic classifications used in this analysis.). Hence, the probability of placing lands in conservation easements (*CEs*) may be summarized in a functional form as:

$$CEs = f(\boldsymbol{R}, \boldsymbol{I}, \boldsymbol{C}, \boldsymbol{G}) \quad (1)$$

Since the dependent variable (*CEs*) is binary (equals one if an individual had placed their land in a conservation easement, and zero otherwise), a probit model was used in preference over an ordinary least square (OLS) model for two reasons. First, probit regression ensures the probability range is between zero and one. In contrast, the OLS model does not ensure the probability estimate will be between zero and one. Second, since the dependent variable is binary, the constant variance (homoscedasticity) assumption of the OLS is violated, whereas the probit regression accommodates it (Wooldridge 2002).

Data

This study used outdoor recreation participation and private land ownership data from the National Survey on Recreation and the Environment (NSRE). The NSRE is a long-term data collection project of the United States Forest Service, Southern Research Station in collaboration with the University of Tennessee and is conducted regularly to see outdoor recreation participation trends across the United States. The NSRE is a random-digit-dialed telephone survey of individuals living in U.S. households. It employs a stratified random sample, based on urban/rural/near-urban geographic locations (Cordell et al. 2004). However, each version of the NSRE consists of different modules or sets of questions and was tested to ensure an average time of 15 minutes to complete. Approximately 5,000 people were surveyed in each version. Some over-sampling was done to ensure a minimum sample size of 500 per state (across all versions) or for some modules that focus on rural outdoor recreation use i.e., over-sampling of people living in rural areas. Both English and Spanish versions of the questionnaires were used and interviews were conducted bilingually to overcome language barriers (Cordell et al. 2004). The survey was conducted using a computer-aided telephone interviewing (CATI) system. The CATI system randomly selects a telephone number, the interviewer upon hearing someone answer inquires how many people in the household are 16 years or older. Of persons 16 or older, the one with the most recent birthday is selected for interviewing (Link and Oldendick 1998) (please visit http://warnell.forestry.uga.edu/nrrt/nsre/Nsre/nsre2.html to know more about the NSRE.).

The NSRE used in this study was conducted in 2005. The 2005 NSRE consisted of four modules or sets of questions related to outdoor recreation activity participation, constraints to participate in wilderness related activities, private land ownership, and

Table 1. Grouping outdoor recreation activities.

Groups	Outdoor recreation activities
Water-based	*Consumptive:* Freshwater fishing; fishing in cold water such as mountain rivers, lakes, or streams for trout; fishing in warm water rivers, lakes or streams for bass, bream, catfish, pike, crappie or perch; saltwater fishing; fishing for ocean-to-freshwater migratory fish such as salmon, shad, or steelhead trout.
	Non-consumptive: Sailing; canoeing; kayaking; rowing; motor-boating; waterskiing; boating using a personal watercraft such as jet skis or wave runners; rafting, tubing or any other type of floating on rivers or other flowing water; sailboarding or windsurfing; surfing; swimming, snorkeling, scuba diving or visit a beach or other waterside area; swimming in an outdoor pool; swimming in streams, lakes, ponds or the ocean; snorkeling; scuba diving; visit beaches for any outdoor recreation activities; visit a waterside other than a beach for recreation activities.
Land-based	*Consumptive*: Gather mushrooms, berries, firewood or other natural products; hunting – hunt big game, hunt small game, hunt waterfowl such as ducks or geese.
	Non-consumptive: Picnicking; gathering of family or friends in an outdoor area away from a home; visit an outdoor nature center, a nature trail, a visitor center or a zoo; visit prehistoric structures or archaeological sites; visit any historic sites, buildings or monuments; attend outdoor concerts, plays or other outdoor performances; attend outdoor sports events; walking for exercise or pleasure; day hiking; orienteering; visit a farm or other agricultural setting for recreation; camp at developed sites with facilities such as tables and toilets; camp at a primitive site without facilities; mountain climbing; rock climbing; caving; visit a wilderness or other primitive, road-less area; home gardening or landscaping for pleasure; view, identify or photograph birds; view, identify or photograph wildlife besides birds; view, identify or photograph salt or freshwater fish; view, identify or photograph wildflowers, trees or other natural vegetation; view or photograph natural scenery; sightseeing; driving for pleasure on country roads or in a park, forest or other natural setting; drive off-road for recreation using a 4-wheel drive, ATV or motorcycle.

migration. In the outdoor recreation participation module, people were asked about their participation in recreation activities over the last 12 months (NSRE 2005). In the sample, all respondents were found to participate in outdoor recreation activities at least once over the last 12 months (please see Table 1 for the lists of activities participated by respondents.). There were three types of respondents – those who only participated in consumptive activities, those who only participated in non-consumptive activities, and those who participated in both – consumptive and non-consumptive activities. In general, consumptive recreationists are more likely to participate in some form of non-consumptive activity in pursuit of their consumptive activities participation. Hence, in data coding, we treated those respondents who participated in both activities as consumptive recreationists. In the private land ownership module, people who indicated they owned one or more parcels of any type of land (e.g., agricultural land, forestland, wetland, or other open space) in rural areas, i.e., outside town or city limits, including their current residence if it was five or more acres in size, were asked about their participation in conservation easements. In the survey, a total of 710 people reported being landholders. However, because of nonresponse errors and/or missing values in one or more of the covariates, the final sample size used for this study was 352 (NSRE 2005).

Data for community characteristics included gross returns per acre (in US $) collected from the U.S. Department of Agriculture (2002); residency location (urban/rural) collected from the NSRE (2005), distance from a major city (in miles), and median housing value (in US $) collected from U.S. Census Bureau (2003). Table 2

Table 2. Definition of variables

Variables	Descriptions
a. Conservation easements; participated = 1	A binary variable that equals one if respondent participated in conservation easements, and zero otherwise
b. Outdoor recreations participation	
· Land-based consumptive recreations; participated =1	A dummy that equals one if respondent participated in consumptive recreations and both (consumptive and non-consumptive) that was land-based, and zero otherwise
· Water-based consumptive recreations; participated =1	A dummy that equals one if respondent participated in consumptive recreations and both (consumptive and non-consumptive) that was water-based, and zero otherwise
c. Individual characteristics	
· Gender; male =1	A dummy that equals one if respondent was male, and zero otherwise
· Income; income > $50,000	A dummy that equals one if respondent had annual income greater than $50,000 a year, and zero otherwise
· Education; college graduated = 1	A dummy that equal one if respondent had at least college degree, and zero otherwise
· Ethnicity; ethnic minorities = 1	A dummy that equals one if respondent belonged to ethnic minorities, such as African-American, Hispanic, and Asian, and zero otherwise
· Age	Age (in year) of respondent
· Parcel of landholding	Total parcel of land (any category) owned that was greater than 5 acres in rural areas, outside town or city limits
· Area of forest holding	Total area of forest owned
· Year of land tenure	Years of land holding
· Family size	Total number of family
d. Community characteristics	
· Gross returns per acre	Gross Crop revenue (in US $) divided by crop acreage at county level
· Median housing value	Median value (in US $) of specified owner-occupied housing units – one-family houses on less than 10 acres without a business or medical office on the property
· Residency location; urban = 1	A dummy that equals one if respondent belonged to metro area, and zero otherwise
· Distance from major city	Average distance (in mile) to the county from major city
e. Geographic regions (base category = South)	
· Geographic region; Rocky Mountain =1	A dummy that equals one if respondent belonged to Rocky Mountain region, and zero otherwise
· Geographic region; North =1	A dummy that equals one if respondent belonged to Northern region and, zero otherwise
· Geographic region; Pacific =1	A dummy that equals one if respondent belonged to Pacific region and, zero otherwise

Note: Besides three variables – yield per acre, median housing value, and distance from major city, all other variables came from the NSRE (2005). Some respondents were found to participate in both activities. However we treated them as consumptive recreationists, as we adopted a dichotomous classification based on whether or not they are consumptive recreationists.

offers definitions and Table 3 shows summary statistics of the variables used in this analysis. The variables conservation easement participation, activity participation, gender, ethnicity, income, education, residency location, and geographic regions were

Table 3. Descriptive statistics of variables used.

	Total Sample (N=352)			
Variables	**Mean**	**Std. Dev.**	**Min**	**Max**
Conservation easements; participated =1	0.22	0.31	0	1
Land-based consumptive recreations; participated =1	0.59	0.49	0	1
Water-based consumptive recreations; participated =1	0.50	0.50	0	1
Gender; male =1	0.51	0.50	0	1
Ethnicity; ethnic minority = 1	0.06	0.16	0	1
Age	48.58	13.77	18	87
Income; income > $50,000= 1	0.48	0.46	0	1
Education; college graduated =1	0.38	0.48	0	1
Parcel of land holding	4.28	10.66	1	85
Area of forest holding (in acre)	33.30	242.35	0	4500
Years of land tenure	15.09	16.57	1	200
Family size	2.64	1.38	1	7
Gross returns per acre (in $)	26.72	41.55	2.36	540.81
Median housing value (in $ '000)	92.50	41.42	32.7	293
Residency; urban = 1	0.37	0.49	0	1
Distance from major city (in mile)	61.70	54.23	0.44	397.58
Geographic region; Rocky mountain =1	0.11	0.30	0	1
Geographic region; North =1	0.37	0.47	0	1
Geographic region; Pacific =1	0.11	0.30	0	1
Geographic region, South =1	0.41	0.49	0	1

all binary variable. In contrast, age, parcel of land owned, area of forest owned, year of land tenure, family size, gross returns per acre, median housing value, and distance from major city were continuous variable. In the sample, 22% of respondents participated in conservation easement programs. Likewise, 59% of respondents participated in some form of land-based consumptive activities and 50% of respondents participated in some form of water-based consumptive activities over the last 12 months. Similarly, 51% of respondents were male, 6% were ethnic minorities, 48% had income above $50,000 a year, 38% were college graduates, and 37% of respondents were urban resident. Regarding geographic regions, 11% of respondents were from the Rocky Mountain, 37% were from the North, 11% were from the Pacific regions, and 41% of respondents were from the South. Respondents were approximately 49 years old, had 4 parcels of landholding, 33 acres of forest holding, 15 years of land tenure, and had 3 household members on average. Regarding the community characteristics of the place they live, it had gross returns per acre of approximately $27, median housing value of approximately $93 thousand, and was 62 miles away from major city (Table 3).

Results and discussion

Table 4 summarizes our findings. The model was statistically significant, as indicated by Wald chi2. The coefficient for the variable land-based consumptive recreation was negative and statistically significant at the five percent level. The predicted probability of placing land under easement was 0.064 smaller for the individual who participated in land-based consumptive activities compared to those who participated in land-based non-consumptive activities. In contrast, the coefficient for the variable water-based consumptive recreation was positive, but was not statistically significant at a conventional level. This finding suggests individuals who participated in land-based consumptive recreation, such as hunting, are less likely to place their lands in conservation easements than their non-consumptive counterparts. However, this relationship does not hold for water-based consumptive recreation, such as fishing. Hence, outdoor recreationists participating in different types of activities may have different environmental orientations and those environmental orientations may vary between clusters of consumptive activities, such as between hunting and fishing. The potential differences in environmental orientation between fishers and hunters could be due to the character of resource consumption involved, and/or there may be different goal orientations between fishers and hunters. Hunting can be viewed as a resource-intensive activity where harvesting game is the primary goal. The degree of catch consumption associated with fishing has been found to vary, depending upon the values and attitudes of different fishers (Dunlap and Heffernan 1975; Theodori et al. 1998). Further, there is some evidence that some recreational fishers placed less emphasis on catching and removing fish and more emphasis on resource preservation (Bryan 1977).

Despite the finding that land-based consumptive recreationists (e.g., hunters) are less likely than their non-consumptive counterparts to supply lands for easements, conservation movements in the United States have benefited greatly from direct and indirect contributions by hunters. Conservation organizations, such as the Rocky Mountain Elk Foundation, Pheasants Forever, Ducks Unlimited, and Wild Turkey Federation have been supported by contributions from hunters. Many of these organizations raise their primary funds from banquets (e.g., hunting heritage superfund banquets, big game banquets, and other annual banquets), where members and volunteers gather for social purpose while purchasing firearms and other merchandise that are exclusive to banquet attendees. These firearms and other merchandise are subject to the Pittman-Robertson excise tax, which is distributed to state wildlife agencies for research and habitat conservation activities. In some cases, hunters have also supported these organizations in conservation and outreach projects through donations. However, most of the donations or funds are likely to come from non-hunters. According to a recent survey, about 13.7 million Americans hunt (U.S. Fish & Wildlife Service 2014), whereas nearly 90 million people are gun-owners in the United States (Gallup Inc 2013), suggesting that hunters compose a relatively small proportion of all contributors to the Pittman-Robertson Fund. Hunters have also supported wildlife habitat protection through the purchase of Duck Stamps in the United States. The

Table 4. Outdoor recreation participation and conservation easements.

VARIABLES	Coefficients	Marginal effects
Land-based consumptive recreation, participated =1	-0.3968**	-0.0642**
	(0.2097)	(0.0341)
Water-based consumptive recreation, participated =1	0.2935	0.0474
	(0.2214)	(0.0356)
Gender, male =1	0.4631**	0.0750**
	(0.2025)	(0.0324)
Ethnicity, nonwhites =1	0.0980	0.0158
	(0.4678)	(0.0756)
Ln(age)	-13.7558***	0.0130
	(5.2154)	(0.0723)
Ln(age) square	1.8160***	
	(0.7040)	
Income, income > $50, 000=1	0.3708*	0.0599*
	(0.2229)	(0.0354)
Education, college graduate=1	0.0964	0.0156
	(0.2015)	(0.0326)
Residency location, urban =1	-0.2906	-0.0469
	(0.2270)	(0.0370)
Family size	0.0460	0.0073
	(0.0790)	(0.0128)
Area of forest owned	-0.0000	-0.0000
	(0.0000)	(0.0000)
Parcel of land owned	0.0152*	0.0024*
	(0.0088)	(0.0012)
Year of land tenure	-0.0042	-0.0006
	(0.0075)	(0.0010)
Gross returns per acre	0.0044**	0.0007*
	(0.0022)	(0.0003)
Ln(median housing value)	-0.5906*	-0.0955*
	(0.3675)	(0.0597)
Ln(distance from major city)	0.0841	0.0136
	(0.1219)	(0.0195)
Geographic region; Rocky Mountain =1	-0.2051	-0.0332
	(0.4099)	(0.0659)
Geographic region; North =1	0.5986**	0.0968**
	(0.2347)	(0.0384)
Geographic region; Pacific =1	0.8501**	0.1377**
	(0.3939)	(0.0642)
Constant	29.9630***	
	(9.7270)	

VARIABLES	Coefficients	Marginal effects
Log likelihood	-101.80	
Wald chi2	35.55	
Prob>chi2	0.012	
Pseudo R2	0.148	
Observations	352	

Note: Robust standard errors are shown in parentheses. ***, **, and * represent results significant at the a = 0.01, 0.05, and 0.1 levels, respectively. The results are robust with the use of logit and tobit models. Note that dependent variable is *acre of land designated to conservation easement* in the tobit model. The results still hold without the use of log transformed age, median housing value, and distance from major city in the probit, logit and tobit models (results not shown here, but available upon requests).

Duck Stamps are adhesive stamp required by the United States government for hunting migratory waterfowl (please visit http://www.fws.gov/duckstamps/Info/Stamps/stampinfo.htm to know more about the Duck Stamps.). Funds from the Duck Stamp are used to purchase and maintain waterfowl habitat and hunting areas through land acquisition and easements. However, a very small proportion of land (about 3%) in the National Wildlife Refuge System was purchased with funds from the Duck Stamp (U.S. Fish & Wildlife Service 2012). Hence, overall, contributions of hunters for environmental conservation and habitat protection are relatively small compared to the non-hunting population. Thus, it is reasonable to argue that consumptive recreationists are less likely to support environmental conservation compared to their non-consumptive counterparts.

Contrary to previous findings that females are more pro-environmental than males regarding a number of environmental issues (Wolkomir et al. 1997; Zelezny et al. 2000), this study found males to be more likely to place their lands in conservation easements than females. The predicted probability of placing land under easement was 0.075 greater for males than for females. This finding may reflect a male dominated land ownership pattern (forest and non-forest lands) in the United States (Butler 2008). Since placing lands under easements is a way to control land use in the future, males in traditional households often are in the role of making major decisions regarding uses of property. Further, placing lands under easements may represent a different type of environmental behavior than was considered in previous studies, such as reading environmental magazines, using recyclable grocery bags or voting for candidates with pro-environmental agendas (e.g., Baldassare and Katz 1992; Wolkomir et al. 1997; Zelezny et al. 2000). Decisions regarding the uses of household property or assets could have relatively longer-term impacts on household resource allocations, while reading environmental literature or using recyclable grocery bags is less likely to have such a lasting impact on household resources.

Consistent with environmental values and awareness literature, income was positively significant suggesting that individuals with higher income are more likely to participate in conservation easements. The predicted probability of placing land under ease-

ment was 0.059 greater for individuals with annual income greater than $50,000 than those whose annual income was less than $50,000. Also, there was a nonlinear relationship between age and the probability of placing lands under easements. As one might expect, the probability of placing lands under easements decreases at an increasing rate as people get older. This finding is consistent with the environmental value or awareness literature (Van Liere and Dunlap 1980). However, the marginal effect of age was not statistically significant at a conventional level. As per conservation easement literature, the findings show having a larger number of parcels of land is positively associated with the probability of placing lands under easements. The marginal effects suggest one additional increase in parcel of landholding increases the predicted probability of placing land under easement by 0.002 although the parcel sizes could vary across landholders.

As per conservation easement literature, the variable gross returns per acre and median housing value are significant, implying that land with higher yield is more likely to be placed under easement and land with higher property price is less likely to be placed under easement. A $100 increase in gross returns per acre increases the predicted probability of placing land under easement by 0.072. In contrast, a one percent increase in housing value decreases the predicted probability of placing land under easement by 0.095. This result most likely reflects a higher opportunity cost of placing lands in easements in counties where land prices are higher. Regarding the geographic regions, the dummies for North and Pacific regions were positively significant, suggesting that individuals in these regions were more likely to place their lands in easements, compared to the South. The predicted probability of placing land under easement was 0.096 greater for individuals in the Northern states and was 0.137 greater for individuals in the Pacific states, compared to the Southern states. This difference may be because of a greater availability of land resources and also land trust organizations in the Pacific and Northern regions, compared to the Southern region (Land Trust Alliance 2014). The variables ethnicity, education, years of land tenure, residency location, family size, area of forest owned, and distance from a major city were not significant in helping to explain the probability of placing lands under an easement.

Conclusion

Consistent with literature and the notion that consumptive recreationists may differ in their sensitivity to environmental issues, this study found empirical evidence to support that land-based consumptive recreationists are less likely than their non-consumptive counterparts to place their land under easements. This finding could be interpreted to suggest that consumptive recreationists, in general, seem less likely to contribute resources for the general environmental or public good purposes, such as restricting the use of land, or the disposition of natural resources on the land compared to their non-consumptive counterparts.

Since this study concerns outdoor recreation participation of the general population and their decisions regarding placement of their lands under easements in the United

States, findings of this study should be taken within that context. These results may not be generalizable to all landowners, who may have different environmental orientations and outdoor recreation activity preferences. We recommend that future studies of conservation easement participation should account for the potential link between landowners' outdoor recreation and their decision regarding easements. Additionally, econometric analyses used in this study evaluate the intention/behavior of a group in general, but may fail to reveal the underlying variations in attitudes/behavior among sub-segments therein. Hence, the results may not be generalizable to specific individuals.

Despite these limitations, the factors identified by this study could be useful to help further understand factors affecting landowners' decisions to place their lands into an easement, particularly the finding that the type of outdoor recreation they participate in can be directly related to their participation in conservation easements. Findings of this study can also be useful for local governments, or land trusts in designing and implementing their easement programs.

References

Baldassare M, Katz C (1992) The personal threat of environmental problems as predictor of environmental practices. Environment and Behavior 24(5): 602–616. doi: 10.1177/0013916592245002

Bjerke T, And CT, Kleiven J (2006) Outdoor recreation interests and environmental attitudes in Norway. Managing Leisure 11(2): 116–128. doi: 10.1080/13606710500520197

Brown P (1995) Race, class, and environmental health: a review and systematization of the literature. Environmental Research 69(1): 15–30. doi: 10.1006/enrs.1995.1021

Bryan H (1977) Leisure value systems and recreational specialization: the case of trout fishermen. Journal of Leisure Research 9(3): 174–187.

Bullard RD (2000) Dumping in Dixie: race, class, and environmental quality. Westview Press, 256 pp.

Butler BJ (2008) Family forest owners of the United States, 2006. General Techical Report NRS-27. U.S. Forest Service, Northern Research Station, Newtown Square, PA.

Cooper JC, Osborn CT (1998) The effect of rental rates on the extension of conservation reserve program contracts. American Journal of Agricultural Economics 80(1): 184–194. doi: 10.2307/3180280

Cordell HK, Betz CJ, Green GT, Mou S, Leeworthy V, Wiley P, Barry J, Daniel H (2004) Outdoor recreation in 21st century America. A report to the nation: the national survey on recreation and the environment. Venture Publishing, State College, PA.

Diamantopoulos A, Schlegelmilch BB, Sinkovics RR, Bohlen GM (2003) Can socio-demographics still play a role in profiling green consumers? A review of the evidence and an empirical investigation. Journal of Business Research 56(6): 465–480. doi: 10.1016/S0148-2963(01)00241-7

Duke JM (2004) Participation in agricultural land preservation programs: parcel quality and a complex policy environment. Agricultural and Resource Economics Review 33: 34–49.

Dunlap RE, Heffernan RB (1975) Outdoor recreation and environmental concern: an empirical examination. Rural Sociology 40(1): 18–30.

Floyd MF, Lee I (2002) Who buys fishing and hunting licenses in Texas? Results from a statewide household survey. Human Dimensions of Wildlife 7(2): 91–106. doi: 10.1080/10871200290089364

Gallup Inc. (2013) Gun owners of America. http://www.statisticbrain.com/gun-ownership-statistics-demographics/

Gatersleben B, Steg L, Vlek C (2002) Measurement and determinants of environmentally significant consumer behavior. Environment and Behavior 34(3): 335–362. doi: 10.1177/0013916502034003004

Geisler CC, Martinson OB, Wilkening EA (1977) Outdoor recreation and environmental concern: a restudy. Rural Sociology 42(2): 241–249.

Ghimire R, Green GT, Poudyal NC, Cordell HK (2014) An analysis of perceived constraints to outdoor recreation. Journal of Park and Recreation Administration 32(4): 52–67.

Guerin D, Crete J, Mercier J (2001) A multilevel analysis of the determinants of recycling behavior in the European countries. Social Science Research 30(2): 195–218. doi: 10.1006/ssre.2000.0694

Gustanski JA (2000) Protecting the land: conservation easements, voluntary actions, and private lands. In: Gustanski JA, Squires RH (Eds) Protecting the land: conservation easements past, present, and future. Island Press, Washington DC and Covelo, California.

Jackson EL (1986) Outdoor recreation participation and attitudes to the environment. Leisure Studies 5(1): 1–23. doi: 10.1080/02614368600390011

Johnston RJ, Duke JM (2007) Willingness to pay for agricultural land preservation and policy process attributes: does the method matter? American Journal of Agricultural Economics 89(4): 1098–1115. doi: 10.1111/j.1467-8276.2007.01029.x

Konyar K, Osborn CT (1990) A national-level economic analysis of conservation reserve program participation: a discrete choice approach. The Journal of Agricultural Economics Research 42(2): 5–12.

Land Trust Alliance (2014) Total acres conserved by local and state land trusts, 2000–2010. http://www.landtrustalliance.org/land-trusts/land-trust-census/data-tables

Link MW, Oldendick RW (1998) Called-Id: does it help or hinder survey research. Annual meeting of the American Association for Public Opinion Research, St. Louis, MO.

Lynch L, Lovell SJ (2003) Combining spatial and survey data to explain participation in agricultural land reservation programs. Land Economics 79(2): 259–276. doi: 10.2307/3146870

NSRE (National Survey on Recreation and the Environment) (2005) National survey on recreation and the environment 2005 Athens, GA: The interagency national survey consortium, coordinated by the USDA Forest Service, Athens, GA and the Human Dimensions Research Laboratory, University of Tennessee, Knoxville, TN.

Peterson MN, Hull V, Mertig AG, Liu J (2008) Evaluating household-level relationships between environmental views and outdoor recreation: the Teton valley case. Leisure Sciences 30(4): 293–305. doi: 10.1080/01490400802165073

Physical Activity Council (2013) Participation report 2013. http://www.physicalactivitycouncil.com/PDFs/2013_PAC_Overview_Report_Final.pdf

Pinhey TK, Grimes MD (1979) Outdoor recreation and environmental concern: a reexamination of the Dunlap-Heffernan thesis. Leisure Sciences 2(1): 1–11.

Porter R, Bright AD (2003) Non-consumptive outdoor recreation, activity meaning, and environmental concern. Paper read at Northeastern Recreation Research Symposium 2003.

Rilla EL, Sokolow AD (2000) California farmers and conservation easements: motivations, experiences, and perceptions in three counties. University of California Agricultural Issues Center.

Stern PC, Dietz T, Kalof L (1993) Value orientations, gender, and environmental concern. Environment and Behavior 25(5): 322–348. doi: 10.1177/0013916593255002

Straughan RD, Roberts JA (1999) Environmental segmentation alternatives: a look at green consumer behavior in the new millennium. Journal of Consumer Marketing 16(6): 558–575. doi: 10.1108/07363769910297506

Tarrant MA, Green GT (1999) Outdoor recreation and the predictive validity of environmental attitudes. Leisure Sciences 21(1): 17–30. doi: 10.1080/014904099273264

Teisl M, O'Brien K (2003) Who cares and who acts? Outdoor recreationists exhibit different levels of environmental concern and behaviour. Environment and Behavior 35(4): 506–522. doi: 10.1177/0013916503035004004

Thapa B (2000) The association of outdoor recreation activities and environmental attitudes and behaviours among forest recreationalists. The Pennsylvania State University.

Thapa B, Graefe AR (2003) Forest recreationists and environmentalism. Journal of Park and Recreation Administration 21(1): 75–103.

Theodori GL, Luloff A, Willits FK (1998) The association of outdoor recreation and environmental concern: reexamining the Dunlap-Heffernan thesis. Rural Sociology 63(1): 94–108.

U.S. Census Bureau (2003) 2003 American community survey. http://www.census.gov/acs/www/library/by_year/2003/

U.S. Department of Agriculture (2002) Agriculture land and agriculture income survey. http://quickstats.nass.usda.gov/

U.S. Fish & Wildlife Service (2012) How long has the federal government been setting aside lands for wildlife? http://www.fws.gov/refuges/about/acquisition.html#money

U.S. Fish & Wildlife Service (2014) Wildlife and sport fish restoration program: national survey – (2011). http://wsfrprograms.fws.gov/Subpages/NationalSurvey/2011_Survey.htm

Van Liere KD, Dunlap RE (1980) The social bases of environmental concern: a review of hypotheses, explanations and empirical evidence. Public Opinion Quarterly 44(2): 181–197. doi: 10.1086/268583

Van Liere KD, Noe FP (1981) Outdoor recreation and environmental attitudes: further examination of the Dunlap-Heffernan thesis. Rural Sociology 46(3): 505–513.

Vaske JJ, Donnelly MP, Hegerlein TA, Shelby B (1982) Differences in reported satisfaction ratings by consumptive and nonconsumptive recreationists. Journal of Leisure Research 14(3): 195–206.

Wolkomir M, Futreal M, Woodrum E, Hoban T (1997) Substantive religious belief and environmentalism. Social Science Quarterly 78(1): 96–108.

Wooldridge JM (2002) Econometric analysis of cross section and panel data. MIT press, Massachusetts.

Zelezny LC, Chua PP, Aldrich C (2000) New ways of thinking about environmentalism: elaborating on gender differences in environmentalism. Journal of Social Issues 56(3): 443–457. doi: 10.1111/0022-4537.00177

Zimmer MR, Stafford TF, Stafford MR (1994) Green issues: dimensions of environmental concern. Journal of Business Research 30(1): 63–74. doi: 10.1016/0148-2963(94)90069-8

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Nature conservation on agricultural land: a case study of the endangered Carnaby's Cockatoo *Calyptorhynchus latirostris* breeding at Koobabbie in the northern wheatbelt of Western Australia

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This paper is dedicated to the late John Doley (1937–2007), whose wise counsel and hard work contributed greatly to the Carnaby's Cockatoo conservation program on Koobabbie.

Abstract

Nature conservation and agricultural production may be considered as conflicting objectives, but for a wheat and sheep property in Western Australia they have been pivotal management objectives for the last 48 years. Koobabbie, a 7,173 ha property, has retained 41.5% of the original native vegetation, and is a designated Important Bird Area by BirdLife Australia, while still being an economically profitable agricultural enterprise. Since 1987 the owners of Koobabbie have kept detailed records of the avifauna of the property, and encouraged staff from government, non-government and academic organisations to conduct research and monitoring of the endangered Carnaby's Cockatoo *Calyptorhynchus latirostris* breeding on their property. In addition, they have instituted control programs for two over-abundant cockatoo species which compete with Carnaby's Cockatoo for nest sites, and for Feral Cats that are predators of

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nesting female Carnaby's Cockatoo and their offspring. This paper presents the results of research and monitoring from 2003-2013, during which seven artificial nesting hollows were erected, and former active nest hollows that had become derelict were repaired. By 2008, the number of breeding pairs on the property was at least 27, but two mass deaths of breeding females in 2009 and 2012 reduced the number of breeding pairs by 80%. This study illustrates the importance of monitoring conservation on private property, and raises a number of issues in relation to management of endangered species dependent on large hollow-bearing trees on private property.

Keywords

Carnaby's Cockatoo, *Calyptorhynchus latirostris*, hollow nesting, nestling condition, wildlife conservation, habitat restoration, endangered species management, ecological and economic sustainability

Introduction

Changes in land use and habitat conversion pose the greatest threats to biodiversity throughout the world. Agricultural intensification is one of the major threats (McNeely et al. 1995). It has resulted in the reduction in the extent and the fragmentation of remaining native vegetation (Saunders et al. 1991). The loss of woodlands and forests pose particular problems for species dependent on hollows (or cavities) in large trees for breeding or shelter sites (Newton 1994). Throughout southern Australia there have been major losses in extent and connectivity of temperate woodlands, and deterioration in the quality of the remainder (State of the Environment Advisory Council 1996, Gibbons and Lindenmayer 2002, Saunders et al. 2003, 2014a). This has a major impact on those species that are dependent on hollows for breeding and shelter (Goldingay 2009, 2011), both in terms of the loss of existing large hollow-bearing trees, and competition for the remaining hollows.

Throughout the world's agricultural zones, nature conservation and intensive agricultural production may be considered as conflicting objectives, but for one wheat and sheep property called Koobabbie in the Waddy Forest district in the northern wheatbelt of Western Australia (WA) (29°56'S; 116°09'E) they have been joint management objectives for the last 48 years.

Koobabbie was not cleared of native vegetation when taken up by Alison Doley's grandparents in 1906. Since then it has been developed as an economically profitable agricultural enterprise by three generations of the same family. In 1966, Alison and John, her late husband, took over management of Koobabbie. Their management objective was ecological and economic sustainability (Doley 1995, 2003). Native vegetation remains on 41.5% of the property, and a further 2.3% of the property was revegetated with native species. Nature conservation features strongly in their management objectives.

Between May 1987 and the end of 1990, the Doleys took part in CSIRO Division of Wildlife and Rangelands Research's atlas of birds in the WA wheatbelt project (Saunders and Ingram 1995). During this project they kept weekly records of every species of bird that occurred on Koobabbie and, at the completion of the atlas project, continued collecting these data until the present. Over the 25 years to 2011, 131

species of bird were recorded on Koobabbie. Their data demonstrated that the property is an important site for the conservation of the region's avifauna (Saunders and Doley 2013), and half of Australia's cockatoo species occur on the property: Red-tailed Black-Cockatoo (*Calyptorhynchus banksii*), Carnaby's Cockatoo (*C. latirostris*), Galah (*Cacatua roseicapilla*), Western Corella (*C. pastinator*), Little Corella (*C. sanguinea*) and Major Mitchell's Cockatoo (*C. leadbeateri*) [bird nomenclature follows Christidis and Boles (1994) with the exception of Carnaby's Cockatoo which follows WA Government legislation]. Of these, Carnaby's Cockatoo and Major Mitchell's Cockatoo are of conservation importance under Western Australian legislation.

In the early and mid-1980s, concern was raised about the impacts of clearing of native vegetation on the distribution, abundance, and breeding success of Carnaby's Cockatoo (Saunders 1982, 1986, Saunders and Ingram 1987). In 1987, the Doleys were alerted to the plight of Carnaby's Cockatoo. They took particular interest in the bird's presence on Koobabbie, and made notes of the cockatoo's breeding activities. In 1999, Alison Doley was appointed to the Carnaby's Cockatoo Recovery Team which had been set up to develop a recovery plan for the species and oversee recovery actions (Cale 2003). Knowing the importance of generating more knowledge about the species, the Doleys encouraged those involved in recovery actions to study Carnaby's Cockatoo and conduct relevant recovery actions for the species on Koobabbie.

Since then, staff, volunteers and students, variously from Birds Australia (now BirdLife Australia), WA Department of Conservation and Land Management (now Department of Parks and Wildlife), Perth Zoo, and Murdoch University have worked on aspects of the ecology, genetics and health of Carnaby's Cockatoo on Koobabbie, as well as carrying out repairs to tree hollows used by the cockatoos, and installing artificial hollows. In addition, land care groups carried out revegetation projects to aid recovery of the species in the district. Although the various research activities and observations of Carnaby's Cockatoo on Koobabbie were not coordinated and, to some extent, have been *ad hoc*, a considerable amount of valuable information on the species has been gathered.

This paper presents the results of the diverse research and monitoring activities conducted on Carnaby's Cockatoo at Koobabbie. It demonstrates that valuable information can be extracted from data collected by volunteers and others on an *ad hoc* basis. It examines the conservation implications resulting from the work, particularly as the property is a designated Important Bird Area, mainly for Carnaby's Cockatoo, and makes recommendations for future conservation management, particularly on private property.

Methods

Study area

Koobabbie is located in the centre of the Northern Agricultural Catchment Council (NACC) area. It is an important area for the conservation of the avifauna of the

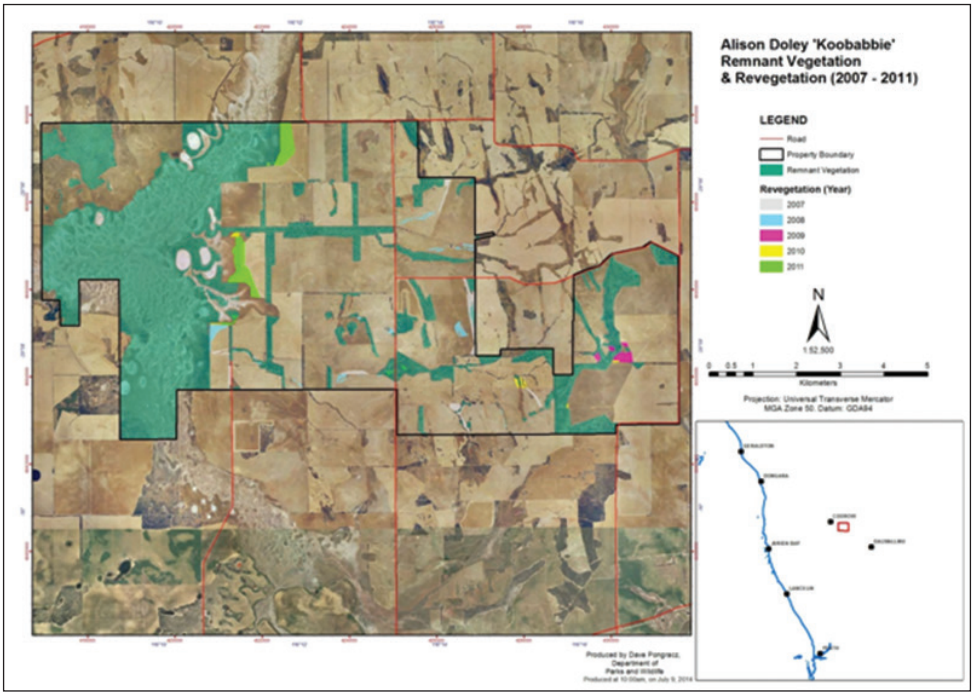

Figure 1. Koobabbie showing property boundary, remnant vegetation, and revegetation 2007–2011).

NACC area (Saunders and Doley 2013). Two hundred and fifty-four hectares of the property are mapped and listed as an important bird area by BirdLife Australia (http://birdlife.org.au/projects/important-bird-areas/iba-maps accessed 9 January 2014) for the support of "up to 32 breeding pairs of the endangered Carnaby's Black-Cockatoo which nest in Salmon Gum on the property", and three other biome-restricted species [Western Corella, Regent Parrot (*Polytelis anthopeplus*) and Blue-breasted Fairy-wren (*Malurus pulcherrimus*)].

Koobabbie has a Mediterranean climate of hot, dry summers and cool, wet winters. The property has a mean annual rainfall of 337 mm (1911–2011 rainfall records from Koobabbie) with 76% of the rainfall occurring between April and September. From 1987 to 2011, total annual rainfall varied from 198.6–560.4 mm. January is the hottest month with a mean daily maximum temperature 36.0 °C and minimum 18.5 °C (data from nearest temperature recording station at Carnamah, 39 km north-west of Koobabbie, Australian Bureau of Meteorology website http://www.bom.gov.au accessed 9th August 2012) and July is the coolest (15.6 °C and 4.6 °C).

The property is 7,173 ha of which 41.5% still retains native vegetation, although 58% of this uncleared land is a major salt lake complex in the property's northeast (Figure 1). Of particular relevance to Carnaby's Cockatoo are the extensive woodland strips that occur throughout the property. These remnants of the original woodlands found in the region are dominated by Salmon Gum (*Eucalyptus salmonophloia*), Gimlet (*E. salubris*) and York Gum (*E. loxophleba*). They provide hollows used for nest

sites by the cockatoos. The remnant vegetation on the deep, yellow, sandy soils mainly found west of Koobabbie includes species of *Banksia*, *Grevillea* and *Hakea* that provide food for the birds. Only 15% of the area within 12 km radius of Koobabbie remains covered with native vegetation (Saunders et al. 2014b).

Between 2007 and 2011, 164.6 ha of revegetation was carried out on Koobabbie (Figure 1). The revegetation is of native species of local provenance. However, it has little value for Carnaby's Cockatoo. The birds nest in the woodland on Koobabbie and forage to the west of the property. Little of the revegetation has been placed where the birds forage and the red clay loam is not suitable for growing species suitable as sources of food. York Gum is the principal species planted in many areas and understorey plants are *Melaleuca* and *Acacia* with no Proteaceae. In slightly saline areas *Atriplex amnicola* has been planted to provide grazing for sheep.

Detailed descriptions of Koobabbie and its management are provided in Doley (1995, 2003) and Saunders and Doley (2013).

Carnaby's Cockatoo

Carnaby's Cockatoo, a large black cockatoo with a distinctive white tail band, is endemic to southwestern Australia. It has been extensively studied (Saunders and Ingram 1998, Saunders et al. 2014b), with one population at Coomallo Creek in the northern wheatbelt of WA being studied in detail from 1969 to the present. In the late 1960s the species was classified as vermin due to its impact on primary production with a bounty on its bill. By the mid-1980s, as a result of destruction and fragmentation of its habitat, it had declined in range and abundance, and became the subject of conservation concern (Saunders 1982, 1990). Currently it is listed as endangered under the Australian *Environment Protection and Biodiversity Conservation Act 1999* and under IUCN Red List category and criteria (IUCN 2014). It is specially protected as "Fauna that is rare or likely to become extinct" in Schedule 1 of the Western Australian *Wildlife Conservation Specially Protected Fauna Notice 2013* under the *Wildlife Conservation Act 1950*. It is the subject of a recovery plan which has recently been revised (Department of Environment and Conservation 2012).

Occurrence data on Carnaby's Cockatoo

From May 1987 to the present, the Doleys recorded every species of bird seen on Koobabbie each week. These data were presence only; for example, one Wedge-tailed Eagle (*Aquila audax*) seen on one occasion during one week was recorded as a tick in the data sheet for that week, as were 100 Western Corella seen every day of the week. In addition, they made notes relating to birds of particular interest. These data and the accompanying notes may be seen on a Supplementary Table to Saunders and Doley (2013) at the journal website http://pcb.murdoch.edu.au. Records of the occurrence

of Carnaby's Cockatoo on the property, together with notes relating to their nesting, behaviour and flock sizes are available from the second half of 1987 to the end of 2013; a period of 28 years.

Carnaby's Cockatoo breeding on Koobabbie

From the breeding season of 2003, staff or volunteers from Birds Australia visited Koobabbie once each year, sometime from late September to early November, and searched for active Carnaby's Cockatoo nests. This was done by looking in each hollow known by the Doleys to be used by Carnaby's Cockatoo, or trees thought to contain a hollow of sufficient size to be suitable for the birds. Any trees with female Carnaby's Cockatoo leaving the hollows or with nestlings or eggs were recorded for subsequent examination. This was carried out by staff from the Department of Conservation and Land Management who recorded the contents of the hollow. If nestlings were large enough to be handled (>3 weeks old), they were measured (length of folded left wing [mm] and body mass [g]), banded (Australian Bird and Bat Banding Scheme bands), and several breast feathers removed for genetic analyses.

The following dimensions were recorded from each hollow used by Carnaby's Cockatoo: height of entrance above ground level (m); diameter of the entrance to the hollow (if circular or the width of the narrowest side, if not circular) (m); depth of the hollow (m); and diameter of the floor of the nest chamber (m). The species of tree providing the hollow was also noted.

Aging of Carnaby's Cockatoo nestlings

Nestlings were aged by comparing the length of their folded left wing (mm) against a reference curve of the length of the folded left wing of known age nestlings from Coomallo Creek, using the method described by Saunders (1986). Saunders (1986) regarded the population at Coomallo Creek as the one in which the nestlings were in the healthiest condition. The accuracy of aging nestlings using this method was ± 4 days applied to nestlings aged around 31 days and ± 6 days applied to nestlings around 64 days. This is a 13% variation at 31 days and 9% at 64 days. This is a reasonable error over a nestling period of more than 70 days. From the nestlings' estimated ages, egg laying dates were extrapolated.

Sexing and kinship of nestlings

Nestlings were sexed based on DNA analysis. DNA-based sex identification targeted the CHD-W and CHD-Z genes located on the sex chromosomes (female, ZW; male, ZZ) using modified primers of Griffiths et al. (1998). Kinship (relatedness) analyses

followed White et al. (2009, 2012) to determine how many and how often individual breeding females nested in hollows on Koobabbie.

Assessment of nestling condition

Saunders (1982) developed a growth curve for Carnaby's Cockatoo based on the relationship between estimated age and expected body mass (g), with standard deviations that ranged from ±20.7% of body mass for nestlings 18 days old, to ±7.4% of body mass for nestlings 68 days old. This reference curve was constructed from measurements of nestlings at Coomallo Creek (1970–1976), 71 km west of Koobabbie. By comparing the observed body mass of nestlings at Koobabbie with their expected body mass relative to their estimated ages based on the measurement of the folded left wing, it was possible to determine which nestlings were in poor condition. Poor condition is defined here as being those nestlings whose body mass was more than one standard deviation below the expected mean body mass for their estimated age (Saunders 1986, Saunders et al. 2014b).

Spacing of active hollows used by Carnaby's Cockatoo

Nearest neighbour analyses, using the distance between the waypoints function on *OziExplorer* GPS Mapping Software, were carried out on all hollow trees used by Carnaby's Cockatoo in the breeding seasons of 2006, 2007 and 2008. These years were chosen because they had the largest number of breeding attempts. In addition, nearest neighbour analyses were carried out on nesting attempts commenced in a series of two-week periods in each of these years. That is, distances (m) to the nearest hollows occupied during weeks 1 and 2 of the breeding season, then weeks 2 and 3, 3 and 4, etc. were calculated. The two-week period was chosen as Saunders (1982) pointed out that females selecting and preparing nest hollows will not tolerate another female prospecting for a nest hollow nearby, but once the female has laid and is incubating, she will tolerate other females nesting as close as hollows in the same tree.

Provision of artificial hollows

On 1 April 2004, seven artificial hollows were erected on Koobabbie. These hollows were constructed of sections of fallen hollow Salmon Gum, with a floor of metal covered with decayed heartwood material from fallen trees, a wooden roof, and an entrance opening to the top and side of the hollow. No measurements were taken of the internal dimensions of artificial hollows, but they were approximately 600–700 mm deep, with an internal diameter of at least 250 mm. They were supported on a

5.8 m length of 100 mm diameter galvanised water pipe. The pipe was supported on a galvanised iron bracket set in concrete with two bolts through the bracket and the pipe, so that by removing one bolt the pipe may be lowered using a front end loader or block and tackle should the hollow need repair. There were several constraints on placement of the artificial hollows; chance of use by Carnabys Cockatoo, vehicle access for erection, and clearance from neighbouring trees. All artificial hollows were erected in woodland known to be frequented by the cockatoos for nesting. Each hollow required access for a tractor with post-hole auger, an eight-tonne truck with 5.8 m of pole and hollow, and a front end loader with a loader bucket. The hollows were placed sufficiently far from neighbouring trees to ensure they would not be damaged should any of those trees fall. The artificial hollows were monitored during the same period natural hollows were monitored.

Control of over-abundant cockatoos and feral cats

Galah and Western Corella compete for hollows with Carnaby's Cockatoo, and in some cases destroy Carnaby's Cockatoo eggs and take over hollows (Saunders 1979, 1982, Alison Doley and Rick Dawson *pers.obs.*). Since November 1989, with appropriate licences, the Doleys have arranged for the destruction of any Galah or Western Corella investigating hollows used by Carnaby's Cockatoo, or in the vicinity of such hollows.

Feral Cats (*Felis catus*) are known to climb trees and prey on cockatoos breeding in hollows, killing nestlings and adults (Saunders 2006). In view of the threats Cats posed to breeding cockatoos, they are controlled on the property opportunistically throughout the year.

Results

Occurrence of Carnaby's Cockatoo on Koobabbie

Carnaby's Cockatoo is a regular breeding visitor to Koobabbie, arriving sometime between the first week in July and the third week in August (median arrival week the last week in July) (Table 1). The birds remain around the property for a period of 22 to 34 weeks (median length of stay 27 weeks) (Table 1), departing sometime between the second week in January and the third week in March (median departure week first week in February) (Table 1). The arrival week of the birds at Koobabbie was significantly correlated ($R^2 = 0.166$; $p = 0.035$) with that year's total Austral autumn rainfall (March to May inclusive) on the coastal plain where they spend the non-breeding season (Figure 2). The wetter the autumn, the earlier the birds arrive at Koobabbie. For example, an increase in annual autumn rainfall of 75 mm advances arrival time by about one week.

Table 1. Week of arrival and departure of Carnaby's Cockatoo at Koobabbie 1987–2013 and the length of time (number of weeks) the birds were on the property. Weeks are numbered from the first week in January with four weeks each month (i.e., 48 recording weeks in the year; for example week 25 is the first week in July).

Week #	25	26	27	28	29	30	31						
# years birds arrived	1	4	7	6	6	2	1						
Week #	2	3	4	5	6	7	8	9	10	11			
# years birds departed	1	2	5	5	6	2	1	2	0	2			
# weeks birds in area	22	23	24	25	26	27	28	29	30	31	32	33	34
# years	1	1	4	3	3	4	3	3	0	2	0	0	1

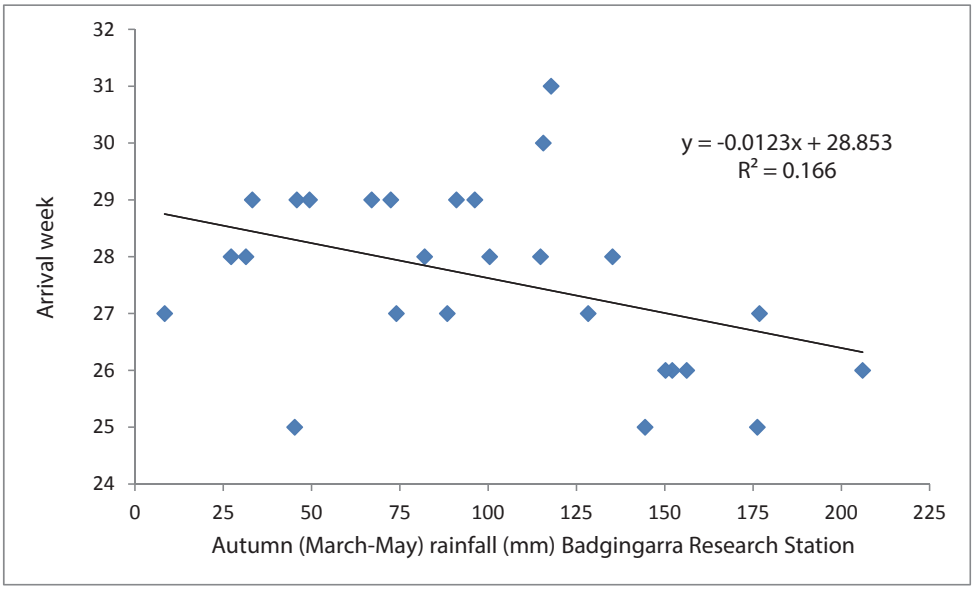

Figure 2. Correlation between week of arrival of Carnaby's Cockatoo at Koobabbie each year (1987–2013), and total autumn rainfall (March-May) each year at Badgingarra Research Station. Rainfall from this station has been used as the birds spend their non-breeding season on the coastal plain from Badgingarra northwards.

Number of breeding attempts 2003–2013

The number of known breeding attempts by Carnaby's Cockatoo at Koobabbie over the 11 years ranged from 18 when monitoring by Birds Australia commenced in 2003, to a maximum of 27 in 2008 (Figure 3). From 2003 to 2013 the number of natural and artificial hollows being monitored increased from 26 to 89. From 2005 to 2013, the monitoring effort for nesting birds was similar. As there were only two monitoring visits each year, these figures represent a minimum number of breeding attempts each year. Accordingly, hollows from which females were flushed on the first visit, that were empty on the second visit, may not have been used, may have been used unsuccessfully, and no evidence remained of the failure, or may have been successful by the time the hollow was checked, but again with no evidence of use.

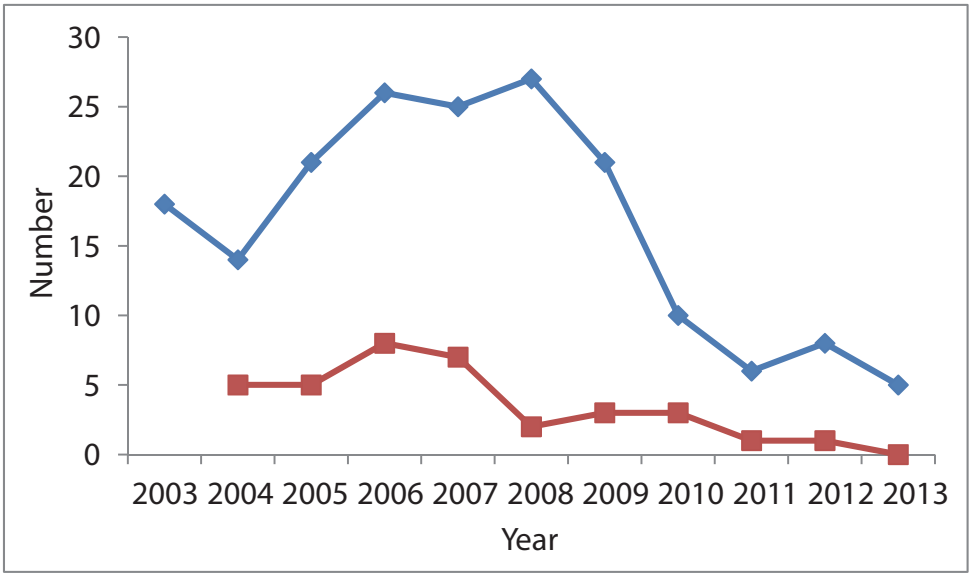

Figure 3. Number of known breeding attempts by Carnaby's Cockatoo at Koobabbie 2003–2013 (diamonds). Known breeding attempts were established by examining the contents of the hollow. Number of female Carnaby's Cockatoo flushed from tree hollows (squares), but the contents were not checked then, or were checked subsequently and no conclusive evidence of a nesting attempt was obtained.

The breeding population in 2009 was less than half that of 2008 due to the death of a number of females, and possibly males. On 30 September 2009, a male Carnaby's Cockatoo was found dragging itself along the ground with its beak. It weighed 434 g, only two-thirds of the average body mass of adult males (Saunders 1974). On 23 October 2009, a mass death of breeding females was recorded with 11 found dead (carcases fly-blown and dried out) in their hollows, and a further five hollows were recorded with abandoned eggs. Four dead females were found on the ground in the nesting area. Dead females were distributed in hollows throughout the woodland areas of Koobabbie, as were the females who successfully bred that season.

There was a similar episode in mid-October 2012, with five females found dead on eggs in their nest hollows. Again, a male with hind limb weakness was found on the ground near the homestead. It was sent for treatment at the Perth Zoo Veterinary Department, but later died. A female found in a moribund state in a nest hollow, was sent to the Perth Zoo Veterinary Department, and later euthanized. Carnaby's Cockatoo feathers on the ground in a belt of woodland indicated an eighth bird had died. These losses again halved the breeding population such that only five breeding attempts were recorded in 2013 (Figure 3); one of these was a second breeding attempt in a hollow where the first attempt failed (Rick Dawson *pers. obs.*).

Necropsies on the two birds found alive, but compromised in 2012, showed no signs of infectious disease or other significant pathological abnormalities, except for the female which had evidence of severe dehydration. Testing was negative for several infectious pathogens including Newcastle disease virus, avian influenza virus, beak

Table 2. Number of first eggs laid by week at Koobabbie 2003–2013. These data relate to the first egg laid in each clutch (clutches of two eggs are most common). No data are available for 2004.

Week	Dates	2003	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
31	Jul 31–Aug 6					1						1
32	Aug 7–13											
33	Aug 14–20					2		1				3
34	Aug 21–27				2	1		1				4
35	Aug 28–Sep 3	2		3	1	4	1	1	1			13
36	Sep 4–10	1	2	4	1	1			2		1	12
37	Sep 11–17	3	2	2	1	4		2	1	1		16
38	Sep 18–24	2		2	2	3						9
39	Sep 25–Oct 1		1	2	4	1		1				9
40	Oct 2–8				3				1			4
41	Oct 9–15		2	1								3
42	Oct 16–22						1					1
43	Oct 23–29						2					2
44	Oct 30–Nov 5											
45	Nov 6–12						1					1
	Total	8	7	14	14	17	5	6	5	1	1	78

and feather disease virus, avian polyomavirus, *Chlamydia psittaci* and avian adenovirus. Screening was negative for 72 toxins including pyrethrins, organophosphates and organochlorines, and testing for seven heavy metals did not reveal any significant findings. It is highly unlikely that food shortage was the cause of the deaths, as one of the males found alive was in good body condition, and some of the nestlings measured that were in unaffected hollows were within the healthy body mass range.

Timing of egg-laying on Koobabbie

During the period 2003–2013, the earliest that egg-laying commenced was Week 31 (Jul 31–Aug 6) in 2008, and the latest Week 45 (Nov 6–12) in 2009 (Table 2). Over all years, 52.6% of eggs were laid during Weeks 35 to 37 (Aug 28–Sep 17). During the breeding seasons of 2006, 2007 and 2008 when most breeding attempts were recorded, egg-laying took place over a 7-9 week period. In the two years after the 2009 mass deaths, egg-laying also took place over a period of seven weeks (2010) and six weeks (2011).

Numbers of Carnaby's Cockatoo seen on Koobabbie

Maximum flock sizes recorded on the property were: 91 (November 1994); 40 (December 1998); 40–60 (December 1999); 58 (October 2001); 98 (November 2004); 46 (December 2007); 26 (September 2009); 18 (September 2010); 23 (November 2011); 18 (August 2012); and 11 or 12 (September 2013).

Feeding observations

Carnaby's Cockatoo were recorded feeding on Wild Radish (*Raphanus raphanistrum*) (an agricultural weed), Wild Geranium or Corkscrew (*Erodium moschatum*) (an agricultural weed), *Banksia prionotes*, *B. attenuata* and *Hakea preissii* on three occasions, and in 2007 on Canola (*Brassica* spp.), an agricultural crop which was first grown in the area in 1998. DNA analyses were used to examine the intestinal content of one of the paralysed birds brought from the field in 2012. The intestines contained plant families Asteraceae, Myrtaceae, Lauraceae, Rutaceae and a clade within asterids known as lamiids.

Sex and kinship of nestlings

DNA-based sex identification was carried out on 75 nestlings sampled from 2003–2010. Of these, 35 were identified as female and 40 as male (Table 3). There was no significant departure from a 1:1 sex ratio (analysis fitting a generalised linear model), which was also the case at Coomallo Creek (Saunders et al. 2013).

From the kinship analyses, fifteen breeding pairs were identified to have visited Koobabbie, at least twice, accounting for 48% of the offspring sample. Thirteen of these pairs were not recorded as breeding in consecutive years. Six pairs used the same tree at least twice.

Condition of nestlings

Seventy-eight nestlings were measured and weighed at Koobabbie between 2003 and 2013 (Table 4). Of these, 13 (16.7%) were more than one standard deviation below the benchmark and deemed to be in poor condition. In 2009, the first year of the

Table 3. Sex of nestlings at Koobabbie (2002–2010) as determined by DNA analysis.

Year	Females	Males	Total
2002	3	2	5
2003	5	4	9
2004	1	1	2
2005	2	4	6
2006	5	6	11
2007	4	13	17
2008	12	8	20
2009	1	0	1
2010	2	2	4
Total	35	40	75

Table 4. Number of nestlings measured at Koobabbie and the number of nestlings whose body mass was one standard deviation below the benchmark body mass (see text for details). The percentages are the proportion of the total nestlings measured that were more than one standard deviation (SD) below benchmark, and deemed to be in poor condition.

Year	# nestlings	# below -1 SD	% below 1 SD
2003	8	3	37.5%
2005	7	0	0%
2006	14	1	7.1%
2007	14	3	21.4%
2008	17	2	11.7%
2009	5	3	60.0%
2010	6	1	16.7%
2011	5	0	0%
2012	1	0	0%
2013	1	0	0%
Total	78	13	16.7%

mass deaths, 60.0% of nestlings were more than one standard deviation below benchmark body mass.

Comparisons were made between data from Koobabbie and data from 963 nestlings at Coomallo Creek (1970–2013) and 73 from Manmanning (1969–1976). Of the Coomallo Creek nestlings, 110 (11.4%; annual range 0–28.6%) were more than one standard deviation below the benchmark body mass, and at Manmanning 46 (63.0%; 14.3–100%) of nestlings were more than one standard deviation below benchmark body mass.

There was a significant negative linear correlation ($R^2 = 0.110$; $p = 0.004$) between time after the commencement of egg-laying for the season and the percentage nestling body mass deviated from the benchmark (Figure 4). The later eggs are laid in the breeding season, the greater the chances the resulting nestlings were in poor condition.

Dimensions of hollows used by Carnaby's Cockatoo on Koobabbie

Carnaby's Cockatoo nested in hollows in 51 trees on Koobabbie, the dimensions of which are given in Table 5. Forty-nine were in Salmon Gum, and one each in Gimlet and York Gum. The mean depth was 1.32 m, which was similar to the depths of hollows in Salmon Gum used by Carnaby's Cockatoo at Manmanning (Saunders 1979). The mean height of hollow entrances was 5.29 m, which was lower than the 7.38 m at Manmanning. However, the range of 2.2–8.7 m indicates that height of entrance is not of major importance; the size of the hollow in the tree is critical (Saunders et al. 2014a).

Of these hollows, 27 (52.9%) needed some form of repair, and three of the hollow-bearing trees (5.9%) had fallen over by the breeding season of 2013.

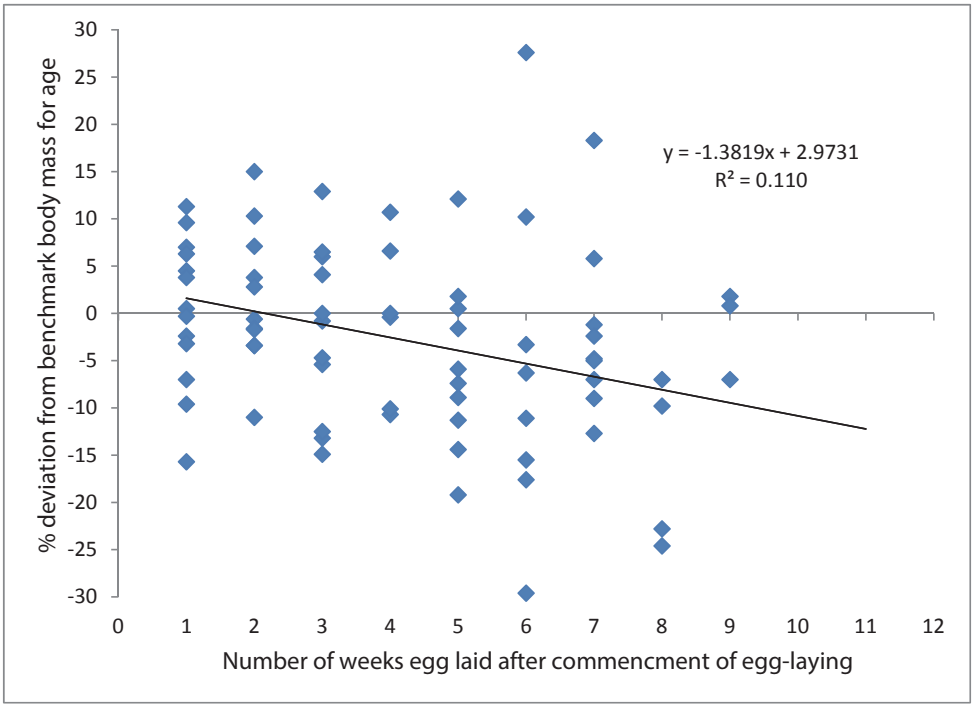

Figure 4. Significant correlation between the percentage of nestlings at Koobabbie whose body mass deviates from the benchmark body mass, and the time at which the egg from which they hatched was laid after the commencement of egg-laying for the season. Egg-laying commenced at Week 1.

Table 5. Dimensions (m) of hollows used by Carnaby's Cockatoo on Koobabbie 2003–2013.

	Height (m)	Depth (m)	Entry Diameter (m)	Floor Diameter (m)
Number	51	49	49	49
Mean	5.29	1.32	0.26	0.33
Median	5.30	1.10	0.25	0.30
St Dev	1.52	0.74	0.08	0.13
Range	2.2–8.7	0.30–3.70	0.10–0.45	0.15–0.70

Spacing of active hollows used by Carnaby's Cockatoo on Koobabbie

Between 2006 and 2008, the average distance between all hollow trees known to be used by Carnaby's Cockatoo at Koobabbie varied from 130 to 180 m (Table 6). However, the average distance between hollow trees in which birds commenced laying at similar times of the breeding season was greater at 600–1050 m. The birds at Koobabbie behave in a similar manner to those at Coomallo Creek, where, over the period 1974–1976, the average distance between the nearest neighbours of all hollows used was 170 ± 10 m, and the average distance between neighbouring hollows laid in a particular week or the previous week was 800 ± 50 m.

Table 6. Average distance (km) to nearest neighbour of all hollow trees used by Carnaby's Cockatoo at Koobabbie during 2006, 2007 and 2008. Also shown is the average distance between nearest neighbours of active hollows started in two-week periods in the same years (see text for details).

	2006	2007	2008	2006–08
Average distance (km) between nearest neighbours of all active hollows	0.18 ± 0.29	0.13 ± 0.16	0.15 ± 0.26	0.13 ± 0.24
Range	0.03–1.23	0.03–0.79	0.03–1.13	0.03–1.2
Average distance (km) between nearest neighbour laid in a particular week or the previous week	1.05 ± 1.02	1.04 ± 1.24	0.60 ± 0.76	0.86 ± 0.99
Range	0.15–3.04	0.13–3.08	0.15–3.10	0.13–3.10

Table 7. Use of the seven artificial hollows installed on Koobabbie before the breeding season of 2004. CC = Carnaby's Cockatoo: E = egg; F = female; N = nestling; RTBC = Red-tailed Black-Cockatoo; and dead refers to the fact that a dead Carnaby's Cockatoo female was found in the hollow.

Nest No	1.10.04	14.10.05	4.10.06	10.10.07	6.11.08	24.10.09	29.09.10	3.10.11	15.10.12	5.11.13	Total
KART 1	F CC	F CC	F CC			F CC					4
KART 2	F CC		F CC 2E		2 CC E		F CC 1E	F CC 1E	Dead CC F 2E		6
KART 3		Galah	Galah		Galah	Galah	Barn Owl				0
KART 4	F CC	F CC 1N	F CC 1N1E	F CC 1N	1 CC N	Dead CC F 1E	1 CC N	F CC 2E			8
KART 5	F CC	F CC 1N1E	F CC 1E	F CC 1N	Galah	1 CC N	RTBC				5
KART 6		Barn Owl	Galah	F CC 1N	Galah						1
KART 7	F CC		F CC 2E	F CC 1N	1 CC N	Dead F CC	F CC		F CC	F CC 1E	8
Total CC	5	3	5	4	3	4	3	2	2	1	

Artificial hollows: costs and use

In 2004, the installation costs of each of the seven artificial hollows were $AUD225 for materials and $AUD330 for labour.

Six were used by Carnaby's Cockatoo at least once over the period 2004 to 2013 (Table 7); 45.7% of the 70 hollow-years they were available. Ten-percent were used by Galah, 2.9% by Barn Owl and 1.4% by Red-tailed Black Cockatoo during the hollow-years available. Artificial Hollow 3 was not used by Carnaby's Cockatoo as the floor of the hollow was too small (Rick Dawson *pers. obs.*). As no follow up visits were made at the end of each breeding season, no data are available on breeding success of birds nesting in artificial hollows.

Movements of Carnaby's Cockatoo from Koobabbie

Eighty Carnaby's Cockatoo nestlings were banded on Koobabbie between 2003 and 2013. It is not known how many of these fledged, or how many returned to breed.

Two fledglings banded at Koobabbie were recorded outside their natal area. One young male was photographed in the Coomallo Creek breeding area on 12 November 2010 (Saunders et al. 2011a). This immature male appeared to be in the company of a female, in a flock that included adults and other immature birds, 71 km west-south-west of its natal area. The second was a female photographed on 12 September 2012, in a flock of up to 400 birds on native vegetation in Beekeepers Nature Reserve, 108 km west of its natal area.

Control of over-abundant cockatoos and feral cats

Of the six cockatoo species occurring on Koobabbie, Galah were the most common; then in decreasing order, Western Corella, Red-tailed Black-Cockatoo, Carnaby's Cockatoo, Major Mitchell's Cockatoo and Little Corella (Alison Doley *pers.obs.*). Galah, Western Corella, Red-tailed Black-Cockatoo and Major Mitchell's Cockatoo were resident on Koobabbie, and Little Corella a vagrant (Saunders and Doley 2013). Galah, Little Corella and Red-tailed Black-Cockatoo were not present in the district prior to clearing of native vegetation for agriculture. These are birds of the arid zone that have extended their range into southwestern Australia as a result of development of agriculture with the provision of grains, agricultural weeds and water for live-stock (Saunders et al. 1985, Saunders and Ingram 1995). Western Corella has increased in numbers on Koobabbie with the development of agriculture (Alison Doley *pers. obs.*), and is present in the district in the thousands.

During September 1995, the Doleys recorded incidents in which Western Corella usurped Carnaby's Cockatoo at five nest hollows known to be used by the latter. In one hollow three Western Corella eggs were removed from the hollow and Carnaby's Cockatoo reclaimed the hollow, and laid two eggs. Subsequently a Western Corella was seen investigating the hollow, and the Doleys found both black cockatoo eggs had holes in the side consistent with them being pecked open. Between 8 February 1997 and 22 March 2014, 11,741 Galah and 4,591 Western Corella were shot on Koobabbie in the vicinity of known black cockatoo nesting hollows.

In October 2007, a female Carnaby's Cockatoo was sitting on two eggs in a hollow in a dead Salmon Gum; this nesting attempt failed as the female was killed by a Cat. Thirty-eight Cats were shot on the property.

Other threats to Carnaby's cockatoo nestlings

During the 2008 breeding season, Alison Doley found Carnaby's Cockatoo nestlings in three hollows were being adversely affected by small black ants (species unknown). This constituted 11% of the hollows known to be used by Carnaby's Cockatoo that season. Previous observations suggested that ants only invaded nest hollows in which there was a dead nestling. In Hollow 24 on 4 December 2008, the nestling was covered

in ants and showing signs of distress. The cloaca and surrounding skin were reddened and scabby. The base of the tree in which the hollow was located was sprayed with chlorpyrifos. The ants were controlled, and by 15 December the nestling had recovered. It fledged on 15 January 2009. One other nestling was found affected by ants. The surrounds of the nest hollow were sprayed, and the nestling fledged on 19 February 2009. No other cases of attack by ants on nestlings were recorded.

Discussion

Carnaby's Cockatoo breeding on Koobabbie

Carnaby's Cockatoo has been a regular breeding visitor to Koobabbie for as long as Alison Doley can remember. Saunders et al. (2013) showed a significant correlation between the commencement of egg-laying and autumn rainfall for birds from Coomallo Creek and Manmanning in which the higher the autumn rainfall, the earlier egg-laying commenced. As data on dates of egg-laying at Koobabbie are limited, week of arrival has been used as an indicator of commencement of breeding. Over the period 1987 to 2012, at Koobabbie Carnaby's Cockatoo conformed to this association with autumn rainfall.

It is difficult to establish a link between the numbers of Galah and Western Corella removed from the local populations, and the steady increase in nesting attempts by Carnaby's Cockatoo. This is in part due to the fact that new nest hollows were still being located after 2005. Anecdotal evidence indicates that the program has been beneficial. For example, in the breeding season of 2007, a Carnaby's Cockatoo commenced breeding in Artificial Hollow 7, but was usurped by a pair of Western Corella. The female Western Corella was shot. The next evening a female Carnaby's Cockatoo was inspecting the hollow; subsequently the hollow was used, with a nestling later banded. Given that the numbers of Major Mitchell's Cockatoo and Red-tailed Black-Cockatoo breeding at Koobabbie also increased during the same period (Alison Doley *pers. obs*.), it seems reasonable to conclude that controlling Galah and Western Corella improved the value of the site for the other three cockatoo species by limiting competition for hollows.

One salient point when considering competition for hollows is that unlike the other cockatoos, which only frequent the nest hollow during the breeding season, Galah guard their breeding hollow throughout the year (Rowley 1990). Galah also have an impact on availability of nest hollows through their destructive habit of "stropping" or chewing the bark away from the trunk of the tree below the nest hollow, in some cases "ring-barking" the tree. This can result in the premature death of the tree (Rowley 1990, Saunders and Ingram 1995: Plate 2).

The six largest artificial hollows were used by Carnaby's Cockatoo during more than half of the hollow-years they were available. Natural hollows formerly used by the cockatoos that were repaired were used soon after being repaired. The rapidity

with which the artificial and repaired hollows were taken up and used indicates that the provision of artificial hollows and repairs of natural hollows are useful strategies for bolstering the stock of nesting hollows.

Condition of nestlings at Koobabbie

Of 60 breeding attempts where nestlings could be measured from 2003 to 2008 (inclusive), 15.0% resulted in nestlings whose body mass were more than one standard deviation below the benchmark established from nestlings at Coomallo Creek. This is similar to the incidence of Coomallo Creek nestlings being in poor condition (11.4%), and much less than the 63.0% recorded at Manmanning. These results indicate that the Koobabbie population was producing healthy nestlings, and was not subject to the same food shortages that led to the extirpation of the population at Manmanning, and a number of other areas throughout the eastern part of the range of the species (Saunders 1986, 1990). However, nestlings raised later in the breeding season are more likely to be in poor condition. This may indicate that food is limited for the population towards the end of the breeding season. It also suggests that, if changes in autumn and winter rainfall patterns continue to occur as predicted (CSIRO 2007, Hennessey et al. 2008), a greater proportion of breeding attempts will occur later in the year, resulting in more low body-mass chicks.

Movements of birds from Koobabbie

The movement records of two fledglings from Koobabbie indicate that the population moves to the coast at the end of the breeding season, and congregates with birds from other breeding populations in the northern wheatbelt (White et al. 2014). One was a four-year-old female, part of a flock of up to 400 birds in the northern sand heaths, west of Eneabba. This is an area where Saunders (1980: Figure 1) reported the Coomallo Creek breeding population and their offspring spend part of the non-breeding season. The other fledgling was a two-year-old male seen in the Coomallo Creek study area. This congregation into groups with other populations provides opportunities for pairs to form in which fledglings from Koobabbie may be mated with fledglings from elsewhere, thus avoiding inbreeding (White et al. 2014). With information on only two fledglings, no light is shed on which sex of fledgling is the one that maintains fidelity to their natal area.

What caused the mass deaths of breeding birds in 2009 and 2012?

Plausible causes of the 2009 deaths include toxicity, infectious disease, or an adverse weather event. Saunders et al. (2011b) ruled out adverse weather as a likely cause because the population at Coomallo Creek was exposed to the same climatic conditions

as the Koobabbie birds and suffered no such mass deaths. Agricultural practices relating to treatment of Canola to prevent insect damage was suggested as a cause. There were no reports of deaths of other species of parrot in the area [including Western and Little Corella, Galah, Major Mitchell's Cockatoo, Red-tailed Black-Cockatoo, Cockatiel (*Nymphicus hollandicus*) and Australian Ringneck (*Barnardius zonarius*)], several of which feed on Canola (Jackson 2009). This may indicate differences in exposure to risk factors due to differing diets, foraging habits or other behaviours.

The reason for the deaths occurring at Koobabbie and not at other similar breeding sites, such as Coomallo Creek, remains unknown, as similar food sources and agricultural practices are present in each area. However, there could be differences in relation to specific methods of agricultural practice, or environmental factors at Koobabbie or adjacent farms that increase the chances of exposure for the birds. What is important is that these data were recorded and shared for future reference (Cox-Witton et al. 2014).

Conservation implications

Koobabbie is the only Western Australian IBA on a private property on which long-term research is encouraged by the owners. This research is important for several reasons. The first relates to Alison and John Doley's approach to conservation. For over 25 years they have kept records of the avifauna of the property, and made the data freely available for others to use (Saunders and Doley 2013). They have conducted fauna and flora surveys of the property, and designated areas of the property for the conservation of the biota, particularly endangered species of plants and animals (Doley 2003). The second is that the Doleys have shown that encouraging and engaging with collaborators from government and non-government conservation agencies, together with those from tertiary institutions, as well as private citizens in the study of Carnaby's Cockatoo over a ten-year period has yielded important results that have application for conservation management, particularly on private property.

Until 2009, the population of Carnaby's Cockatoo on Koobabbie was regarded as one of the most important in the northern wheatbelt. There were at least 27 pairs breeding on the property, and active research and management was carried out. As a result, Koobabbie was known colloquially as "Cockatoo Club Med." However, without this long-term study involving many individuals and organisations, the impact of the 2009 and 2012 mass deaths may have gone unreported. These catastrophic events reduced the breeding population by approximately 80%, and illustrate the impact of stochastic events. The danger is that with such small numbers now breeding on Koobabbie, other factors may come into play and lead to the extirpation of Carnaby's Cockatoo on the property, as has happened in other areas of the range of the species (Saunders 1990).

Knowing that large hollow-bearing trees are being lost on Koobabbie, and replacement stock takes a century or more to provide a hollow for Carnaby's Cockatoo (Mawson and Long 1994), artificial hollows were erected and maintained, and derelict

hollows formerly used by Carnaby's Cockatoo repaired. Both strategies were successful in increasing availability of hollows and were used. These are essential management actions, and should be continued as long as required. However, unless there is a major planting of Salmon Gum to replace the losses of existing trees over the long-term, the woodland will continue to degrade and there will be few large hollow-bearing trees in future (Saunders et al. 2003, 2014a). This illustrates the need to plan for the long-term future, as any revegetation now will only result in useable hollows well into the next century. In undertaking revegetation it is important to consider the potential impacts of climate change. Under changed climatic conditions it may be necessary to revegetate with Salmon Gum from the more arid parts of their distribution, as they are likely to contain arid-adapted genes (Steane et al. 2014), and may be more likely to survive than plants of local provenance (Breed et al. 2013).

As a result of changes in land use in the southwest of WA, conditions have favoured some species, which have increased in range and/or abundance, including Galah and Western Corella (Saunders et al. 1985, Saunders and Ingram 1995, Barrett et al. 2003). Galah and Little Corella have colonised Kangaroo Island, where they compete with Glossy Black-Cockatoo (*Calyptorhynchus lathami*) for nest hollows (Garnett et al. 1999). Garnett et al. (1999) noted that "management to check the growth of both Galah and Little Corella populations is therefore desirable in Glossy Black Cockatoo breeding areas." Between 1998 and 2004, 486 Little Corella were shot (Mooney and Pedler 2005); a rate of 81 birds/year. They regarded this culling as successful because the Little Corella population increased in some areas, and no nestling Glossy Black-Cockatoo deaths were recorded. However, Harris et al. (2012) conducted a population viability analysis of the Glossy Black-Cockatoo (GBC) population on Kangaroo Island, and noted that the "reduction in corella management indicates this culling was almost negligible because of the resilient GBC population." They ran their model on the basis of two Glossy Black-Cockatoos being lost each year to Little Corella, and recommended that culling could be stopped in some areas to conserve management resources. No information was provided on Galah control, if it took place. At Koobabbie, the rate of culling of Galah and Western Corella was 1256 birds/year; a rate 15.5 times that of the rate on Kangaroo Island, indicating a much higher density of nest competitors. We believe that culling is a management action that should be carried out in areas where there is competition for tree hollows between over-abundant cockatoos and endangered species.

It is ironic that Koobabbie has been also designated as an IBA for Western Corella, when it has been subject to control on the property. Western Corella is common through much of the northern wheatbelt with flocks of up to 3,000 seen at Dalwallinu (60 km south-east of Koobabbie), Dongara (143 km north-west), Geraldton (197 km north-west), and Morawa (80 km north) (http://www.dec.wa.gov.au/pdf/plants_animals/living_with_wildlife/1905_butlers_corella.pdf accessed 21 April 2014). Alison Doley is aware that some management for agricultural production favours Western Corella and Galah. Unlike properties surrounding Koobabbie, Koobabbie continues to maintain sheep with 2,400 breeding ewes. For many years, during the

Austral autumn, sheep were fed oats which were spread along the ground in a trail. A few years ago, lupins were grown in the area and added to the trail-feed. Sheep prefer lupins to oats, and consumed lupins first, leaving most of the oats to Western Corella and Galah, which do not feed on lupins. About four years ago, the Doleys ceased supplying oats in the trail-feed. In 2013, 12 lick-feeders were purchased, and in future sheep will be fed oats and lupins from these, reducing the quantity of oats available to cockatoos. Although oats are grown on the property, sheep eat much of the grain left in the stubble after harvest. However, as neighbouring properties do not stock sheep, Western Corella and Galah have wheat available in stubble paddocks in autumn.

Saunders et al. (2014b) suggested that Carnaby's Cockatoo's adaptation of Canola as a food source may have been beneficial to some breeding populations throughout its range. However, the mass deaths at Koobabbie in 2009 and 2012 indicate that further investigation is warranted to determine if there are any agricultural chemicals which may be adversely affecting populations dependent on Canola. Further, there is a lack of understanding about the nutritional benefit of Canola for Carnaby's Cockatoo, as well as the amount of native food sources in addition to introduced plant species, that are required to provide balanced nutrition for breeding birds.

If Canola as a feed source is beneficial to Carnaby's Cockatoo, it should not be used to justify the continued clearing of native proteaceous vegetation. This can now occur under the WA native vegetation clearing regulations, which allow isolated trees and up to 5 ha/year to be cleared without the need for a licence to clear (Environmental Protection Authority 2004). The cumulative impact of the current level of clearing on farms, as well as on road and railway reserves during maintenance activities, continues to reduce the availability of native food, and increases the dependence on agricultural crops such as Canola and other exotic vegetation such as Pines (*Pinus* spp.). Any potential for an increased level of clearing would only exacerbate matters.

At present there is no quantitative estimate of the extent of private property providing breeding and feeding habitat for the species. It is also important that the extent of suitable habitat is established, and incentives developed to encourage more farmers to emulate the example of the Doleys in making nature conservation an objective of their management, and monitoring the outcomes of that management.

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References

Barrett G, Silcocks A, Barry S et al. (2003) The New Atlas of Australian Birds. Royal Australasian Ornithologists Union, Melbourne, 1–824.

Breed MF, Stead MG, Ottewell KM et al. (2013) Which provenance and where? Seed sourcing strategies for revegetation in a changing environment. Conservation Genetics 14: 1–10. doi: 10.1007/s10592-012-0425-z

Cale B (2003) Carnaby's Black-Cockatoo (*Calyptorhynchus latirostris*) Recovery Plan 2002–2012. Western Australian Department of Conservation and Land Management, Wannaroo, Western Australia, 1–29.

Christidis L, Boles WE (1994) The taxonomy and species of birds of Australia and its territories. Monograph 2. Royal Australasian Ornithologists Union, Hawthorn East, Victoria, 1–29.

Cox-Witton K, Reiss A, Woods R et al. (2014) Emerging Infectious Diseases in Free-Ranging Wildlife–Australian Zoo Based Wildlife Hospitals Contribute to National Surveillance. PLoS ONE 9(5): e95127. doi: 10.1371/journal.pone.0095127

CSIRO (2007) Climate Change in Australia. Technical Report 2007. CSIRO and Bureau of Meteorology.

Department of Environment and Conservation (2012) Carnaby's Cockatoo (*Calyptorhynchus latirostris*) Recovery Plan. Western Australian Wildlife Management Program No. 52. Department of Environment and Conservation, Perth, Western Australia, 1–56.

Doley A (1995) Networks needed by individual farmers: a personal perspective from the Northern Wheatbelt of Western Australia. In: Saunders DA, Craig JL, Mattiske EM (Eds) Nature Conservation 4: the Role of Networks. Surrey Beatty & Sons, Chipping Norton, New South Wales, 241–250.

Doley A (2003) "Koobabbie": ecological and economic sustainability. Pacific Conservation Biology 9: 42–48.

Environmental Protection Authority (2004) Environmental Protection (Clearing of Native Vegetation) Regulations 2004. Amendments published 4 December 2013. http://www.slp.wa.gov.au/legislation/statutes.nsf/main_mrtitle_1384_homepage.html [accessed 28 July 2014]

Garnett ST, Pedler LP, Crowley GM (1999) The breeding biology of the Glossy Black-Cockatoo *Calyptorhynchus lathami* on Kangaroo Island, South Australia. Emu 99: 262–279 doi: 10.1071/MU99032

Gibbons P, Lindenmayer D (2002) Tree hollows and wildlife conservation in Australia. CSIRO Publishing, Melbourne, Victoria, 1–211.

Goldingay RL (2009) Characteristics of tree hollows used by Australian birds and bats. Wildlife Research 36: 394–409. doi: 10.1071/WR08172

Goldingay RL (2011) Characteristics of tree hollows used by Australian aboreal and scansorial mammals. Australian Journal of Zoology 59: 277–294. doi: 10.1071/ZO11081

Griffiths R, Double MC, Orr K, Dawson RJG (1998) A DNA test to sex most birds. Molecular Ecology 7: 1071–1075. doi: 10.1046/j.1365-294x.1998.00389.x

Harris JBC, Fordham DA, Mooney PA et al. (2012) Managing the long-term persistence of a rare cockatoo under climate change. Journal of Applied Ecology 49: 785–794. doi: 10.1111/j.1365-2664.2012.02163.x

Hennessy K, Fawcett R, Kirono D et al. (2008) An Assessment of the Impact of Climate Change on the Nature and Frequency of Exceptional Climatic Events. Commonwealth of Australia, Barton, Australian Capital Territory. http://www.daff.gov.au/__data/assets/pdf_file/0007/721285/csiro-bom-reportfuture-droughts.pdf [accessed 4 July 2011]

IUCN (2014) The IUCN Red List of Threatened Species. Version 2014.2. http://www.iucnredlist.org [accessed 28 July 2014]

Jackson C (2009) Assessing and quantifying canola crop damage by Carnaby's Black-Cockatoo *Calyptorhynchus latirostris* in the south-west of Western Australia. M.Sc. thesis, University of Sydney, New South Wales.

Mawson PR, Long JL (1994) Size and age parameters of nest trees used by four species of parrot and one species of cockatoo in South-west Australia. Emu 94: 149–155. doi: 10.1071/MU9940149

McNeely JA, Gadgil M, Leveque C et al. (1995) Human influences on biodiversity. In: Heywood VH, Watson RT (Eds) Global Biodiversity Assessment. Cambridge University Press, Cambridge, 711–821.

Mooney PA, Pedler LP (2005) Recovery Plan for the South Australian subspecies of the Glossy Black-Cockatoo (*Calyptorhynchus lathami halmaturinus*): 2005-2010. Department of Environment South Australia.

Newton I (1994) The role of nest sites in limiting the numbers of hole-nesting birds: a review. Biological Conservation 70: 265–276. doi: 10.1016/0006-3207(94)90172-4

Rowley I (1990) Behavioural ecology of the galah *Eolophus roseicapillus* in the wheatbelt of Western Australia. Surrey Beatty & Sons in association with the Commonwealth Scientific and Industrial Organisation, Division of Wildlife and Ecology and the Royal Australasian Ornithologists Union, Chipping Norton, New South Wales, 1–188.

Saunders DA (1974) Subspeciation in the White-tailed Black Cockatoo, *Calyptorhynchus baudinii*, in Western Australia. Australian Wildlife Research 1: 55–69. doi: 10.1071/WR9740055

Saunders DA (1979) The biology of the short-billed form to the White-tailed Black Cockatoo, *Calyptorhynchus funereus latirostris* Carnaby. Ph. D. Thesis, University of Western Australia, Crawley, Western Australia.

Saunders DA (1980) Food and movements of the short-billed form of the White-tailed Black Cockatoo. Australian Wildlife Research 7: 257–269. doi: 10.1071/WR9800257

Saunders DA (1982) The breeding behaviour and biology of the short-billed form of the White-tailed Black Cockatoo *Calyptorhynchus funereus*. Ibis 124: 422–455. doi: 10.1111/j.1474-919X.1982.tb03790.x

Saunders DA (1986) Breeding season, nesting success and nestling growth in the Carnaby's cockatoo *Calyptorhynchus funereus latirostris* over 16 years at Coomallo Creek and a method for assessing the viability of populations in other areas. Australian Wildlife Research 13: 261–73. doi: 10.1071/WR9860261

Saunders DA (1990) Problems of survival in an extensively cultivated landscape: the case of Carnaby's Cockatoo *Calyptorhynchus funereus latirostris*. Biological Conservation 54: 111–124. doi: 10.1016/0006-3207(90)90057-V

Saunders DA (2006) Cats and cockatoo chicks. In: Olsen P, Silcocks A, Weston M (Eds) The State of Australia's Birds 2006: Invasive Species. Birds Australia, Hawthorn East, Victoria, 13.

Saunders DA, Doley A (2013) The birds of "Koobabbie" in the northern wheatbelt of Western Australia (1987–2011) and the contribution of the farm to conservation of the region's avifauna. Pacific Conservation Biology 19: 204–232.

Saunders DA, Hobbs RJ, Margules CR (1991) Biological consequences of ecosystem fragmentation: a review. Conservation Biology 5: 18–32. doi: 10.1111/j.1523-1739.1991.tb00384.x

Saunders DA, Ingram JA (1987) Factors affecting survival of breeding populations of Carnaby's Cockatoo *Calyptorhynchus funereus latirostris* in remnants of native vegetation. In: Saunders DA, Arnold GW, Burbidge AA, Hopkins AJM (Eds) Nature Conservation: the Role of Remnants of Native Vegetation. Surrey Beatty & Sons, Chipping Norton, New South Wales, 249–258.

Saunders DA, Ingram JA (1995) Birds of Southwestern Australia. An Atlas of Changes in Distribution and Abundance of the Wheatbelt Avifauna. Surrey Beatty & Sons, Chipping Norton, New South Wales, 1–296.

Saunders DA, Ingram JA (1998) Twenty-eight years of monitoring a breeding population of Carnaby's Cockatoo. Pacific Conservation Biology 4: 261–270.

Saunders DA, Dawson R, Mawson P (2011a) Photographic identification of banded Carnaby's Black Cockatoos. Corella 35: 52–54.

Saunders DA, Mawson P, Dawson R (2011b) The impact of two extreme weather events and other causes of death on Carnaby's Black Cockatoo: a promise of things to come for a threatened species? Pacific Conservation Biology 17: 141–148.

Saunders DA, Mawson PR, Dawson R (2014a) Use of tree hollows by Carnaby's Cockatoo and the fate of large hollow-bearing trees at Coomallo Creek, Western Australia 1969–2013. Biological Conservation 117: 185–193. doi: 10.1016/j.biocon.2014.07.002

Saunders DA, Mawson PR, Dawson R (2014b) One fledgling or two in Carnaby's Cockatoo (*Calyptorhynchus latirostris*) – a strategy for survival or legacy from a bygone era? Conservation Physiology 2. doi: 10.1093/conphys/cou001

Saunders DA, Smith GT, Ingram JA, Forrester RI (2003) Changes in a remnant of salmon gum *Eucalyptus salmonophloia* and York gum *E. loxophleba* woodland, 1978 to 1997.

Implications for woodland conservation in the wheat-sheep regions of Australia. Biological Conservation 110: 245–256. doi: 10.1016/S0006-3207(02)00223-9

Saunders DA, Rowley I, Smith GT (1985) The effects of clearing for agriculture in the distribution of cockatoos in the southwest of Western Australia. In: Keast A, Recher HF, Ford H, Saunders D (Eds) Birds of Eucalypt Forest and Woodlands: Ecology, Conservation, Management. Surrey Beatty & Sons, Chipping Norton, New South Wales, 309–321.

Saunders DA, Wintle BA, Mawson PR, Dawson R (2013) Egg-laying and rainfall synchrony in an endangered bird species; implications for conservation in a changing climate. Biological Conservation 161: 1–9. doi: 10.1016/j.biocon.2013.02.004

State of the Environment Advisory Council (1996) State of the Environment: Australia 1996. CSIRO Publishing, Collingwood, Victoria.

Steane DA, Potts BM, McLean E et al. (2014) Genome-wide scans detect adaptation to aridity in a widespread forest tree species. Molecular Ecology 23: 2500–2513. doi: 10.1111/mec.12751

White NE, Bunce M, Mawson PR et al. (2014) Identifying conservation units after large-scale landclearing: a spatio-temporal molecular survey of endangered white-tailed black-cockatoos (*Calyptorhynchus* spp.). Diversity and Distributions. doi: 10.1111/ddi.12202

White NE, Dawson R, Coghlan ML et al. (2012) Application of STR markers in wildlife forensic casework involving Australian black-cockatoos (*Calyptorhynchus* spp.). Forensic Science International: Genetics 6: 664–670. doi: 10.1016/j.fsigen.2011.10.003

White NE, Mawson PR, Dawson R et al. (2009) Characterisation and cross-species utility of 20 microsatellite markers for population and forensic applications in the endangered Carnaby's Black-cockatoo, *Calyptorhynchus latirostris*. Conservation Genetics Resources 1: 341–345. doi: 10.1007/s12686-009-9079-7

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DATA PAPER

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Life-history trait database of European reptile species

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Abstract

Life-history data are essential for providing answers to a wide range of questions in evolution, ecology, and conservation biology. While life history data for many species, especially plants, are available online, life history traits of European reptiles are available only widely scattered in different languages and primarily in printed media. For this reason, we generated a comprehensive trait database covering all European reptile species. Data were compiled by searching the peer-reviewed and non-peer-reviewed literature. The database covers the whole of Europe and neighbouring Asian and African countries. Traits were categorised under five main headings: Activity / Energy / Habitat; Phenology; Movement; Sexual Maturity; and Morphometry. To ensure that the data were standardised, we defined trait data categories before we started compiling data. All entries were checked by at least one other person. The dataset provides a unique source for meta-analyses and modelling in ecology and conservation biology.

Keywords

Activity, Europe, life history traits, lizards, movement, phenology, Reptilia, Sauria, Serpentes, Testudines

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Introduction

Large-scale analyses of drivers of biodiversity, biodiversity patterns, and global processes are gaining increasingly more importance in ecology and conservation science. Recent examples of large-scale analyses and meta-analyses on biodiversity investigated among other aspects the minimum area requirements of species (Pe'er et al. 2014), the scaling behaviour of beta-diversity (Keil et al. 2012), dispersal (Stevens et al. 2010), niche ecology (Kearney and Porter 2009, Schulte et al. 2012), the effects of climate warming on biodiversity (Deutsch et al. 2008, Sinervo et al. 2010), the effects of fragmentation of tropical forests on climate change (Pütz et al. 2014), and the monitoring of land use effects on biodiversity (Kuussaari et al. 2007, Kahl and Bauhus 2014).

Species traits play an important role in such large-scale analyses since they can affect but also respond to abiotic and biotic processes (Kleyer 1999, Chapin et al. 2000, Ilg et al. 2012, Pütz et al. 2014). Available trait information for some species also enables generalisations to species for which the trait is difficult to measure. This is of particular importance in applied biodiversity conservation when decisions have to be made for species for which knowledge is limited. .This is the case, for example, for dispersal potential in the assessment of connectivity (Stevens et al. 2010, 2013), minimum area requirements in the design of conservation areas (Pe'er et al. 2014), and the identification of species that are sensitive to fragmentation (Henle et al. 2004). The use of traits can therefore greatly improve our understanding of ecological patterns and processes and their relevance for the conservation of biodiversity.

Trait data are usually published in widely dispersed literature and therefore difficult to access. Hence, a compilation of such data in handbooks (e.g. Novosolov et al. 2013) or in databases is essential to support the study of large-scale ecological processes and patterns. Due to their key role in ecosystem processes, traits for several groups of species have been compiled and made available, e.g. several plant traits [Klotz et al. 2003 (www.biolflor.de), Kleyer et al. 2008 (www.leda-traitdatabase.org), Kattge et al. 2011 (www.try-db.org)], bees [Bees, Wasps & Ants Recording Society 2014 (www.bwars.com)], syrphids [Speight et al. 2000 (www.iol.ie/~millweb/syrph/syrphid.htm)], butterflies [Jonko et al. 2014 (http://www.lepidoptera.eu/)], amphibians [Trochet et al. 2014 (http://biodiversitydatajournal.com/articles.php?id=4123)], and birds [Koposová et al. 2014 (http://scales.ckff.si/scaletool/index.php?menu=6)]. However, we are not aware of a global species trait database that exists for reptiles although a general compilation of reptile species names and distribution exists (Uetz and Hošek 2014) and a compilation of trait data have been published in printed form e.g. for Mexico (Sinervo et al. 2010) and some selected traits of 641 lizard species from around the world (Novosolov et al. 2013). For this reason, within the project SCALES (Henle et al. 2010) we developed a trait database covering all European reptile species since the project was predominantly based in Europe. We mainly aimed to obtain phenological and movement data from across the geographic distribution of the species covered. However, other information on activity, energy, habitat, sexual maturity, and morphometry were also included.

The reptile trait database is an open access database. A user-friendly interface including browse options is provided on the SCALES project webpage (http://scales.ckff.si/scaletool/), but we also provide access to raw data through Dryad (doi: 10.5061/dryad.hb4ht). We will keep the database active and update it frequently. We therefore invite all of our readers to provide published data that can be added to the database. If you are interested in submitting data, please contact the authors and send the respective papers. The data will be checked by us for plausibility (especially non-peer-reviewed publications) before being entered into the database.

Data resources

Data published through Dryad: http://dx.doi.org/10.5061/dryad.hb4ht
Data published through SCALETOOL: http://scales.ckff.si/scaletool/?menu=6&submenu=0

Project details

Project title: Securing the conservation of biodiversity across administrative levels and spatial, temporal, and ecological scales (SCALES) (Henle et al. 2010)
Subproject: Trait database of reptile life histories
Personnel: Klaus Henle (Project Coordinator, Taxonomic Expert, and Data Compilation), Annegret Grimm (Data Compilation and Data Manager), Ana María Prieto Ramírez (Data Compilation), Sylvain Moulherat (Data Compilation), Julie Reynaud (Data Compilation)
Funding: FP7 integrated project SCALES; EU Grant no. 226852

Taxonomic coverage

General taxonomic coverage description: The coverage of this database spans the class of Reptilia in the Kingdom Animalia. The database collates the species traits of all 122 European species belonging to 43 genera recognized by the SEH Atlas of 2004 (Gasc et al. 2004), which was the most up-to-date list when we started our data compilation (referred to as *SEH taxonomy* in the database; Suppl. material 1: Table S1). Since the atlas was published, many names changed both at and below the generic level, primarily by splitting previous taxa. Currently, there are several lists of European reptile species available (Sindaco and Jeremčenko 2008, Cox and Temple 2009, Speybroeck et al. 2010, Mayer 2013, Glandt 2014, Sillero et al. 2014, Uetz and Hošek 2014) that deviate from each other in recognition of some taxa and also in terms of geographic coverage (see below). Unfortunately, justifications for the acceptance or rejection of taxa are rather limited for several of these lists, with Speybroeck et al. (2010) being

the most comprehensive one. We therefore largely followed them but evaluated several more recent name changes by using original publications. We agree with Speybroeck et al. (2010) that the scientific name of a species should only be changed if there is strong evidence of it being necessary to reflect evolutionary history and if data are supported by sound evidence. On the other hand, further taxon splitting is a necessary consequence of advances in systematics. Strong evidence for us means that a name change is backed by sufficiently comprehensive sampling, by consistent evidence from more than one character set analysed with appropriate statistical methods, and by sound biogeographic scenarios. For inclusion in the database, an additional criterion had to be fulfilled: the distribution of the taxa involved must have been worked out sufficiently to allow allocation of life-history data to a particular taxon without uncertainty. This resulted in 144 recognized species belonging to 59 genera (named *current taxonomy* in the database; Suppl. material 1: Table S1). Deviations from Speybroeck et al. (2010) and Sillero et al. (2014) are listed and justified in Suppl. material 2: Table S2. The database is designed in such a way that taxa (European or non-European) can be added without a need to change the structure of the database. The database can be searched using both the original names as in Gasc et al. (2004) as well as the updated names. We allocated data that were published before species complexes were split to the relevant new taxa if this allocation could be made with certainty.

Taxonomic ranks

Kingdom: Animalia.
Phylum: Chordata.
Class: Reptilia.
Order: Testudines, Squamata (Amphisbaenia, Sauria, Serpentes).
Family: Agamidae, Anguidae, Blanidae, Boidae, Chamaeleonidae, Cheloniidae, Colubridae, Dermochelyidae, Emydidae, Gekkonidae, Geomyidae, Lacertidae, Lamprophiidae, Natricidae, Phyllodactylidae, Scincidae, Sphaerodactylidae, Testudinidae, Typhlopidae, Viperidae.
Family names of reptiles also changed since 2004. Our list follows the family names accepted in the TIGR global reptile database (Uetz and Hošek 2014).
Common Name: Reptiles, Snakes, Lizards, Tortoises.

Spatial coverage

General spatial coverage: Our database covers Europe. Neither politically nor geographically has the boundary of Europe been universally agreed upon and overviews of the distribution of reptile species used different existing delimitations (Mertens and Wermuth 1960, Böhme 1981, Gasc et al. 2004, Cox and Temple 2009, Speybroeck et al. 2010, Sillero et al. 2014). We followed Mertens and Wermuth (1960,) Böhme

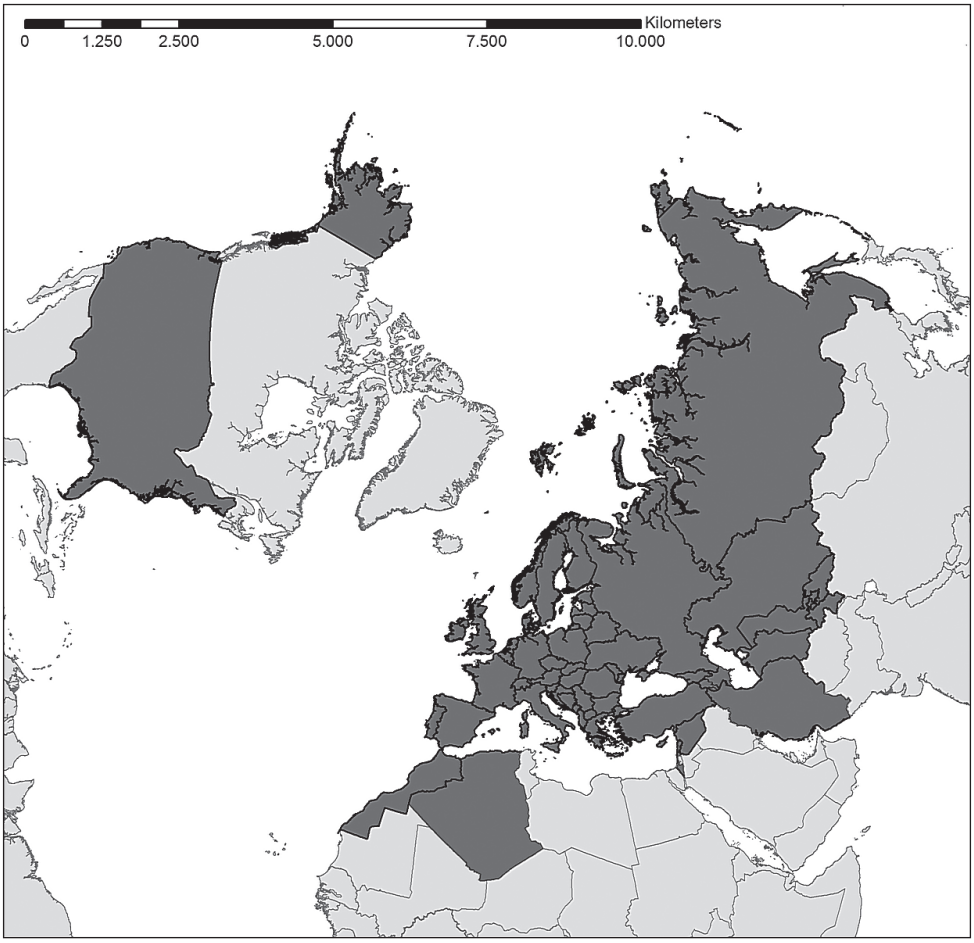

Figure 1. Spatial coverage of the database. Grey countries (46 European countries plus neighbouring countries in Asia, namely Armenia, Azerbaijan, Georgia, Iran, Israel, Kazakhstan, Kyrgyzstan, Lebanon, Russia, Syria, Tajikistan, Turkey, Turkmenistan, and Uzbekistan, plus the African countries Algeria and Morocco) are covered by the database. This map shows the countries in general and not the region where data points are from. This map was created using ArcGIS® software by Esri (www.esri.com) with an European Lambert Azimuthal Equal Area projection. © Esri, all rights reserved.

(1981), and Gasc et al. (2004), using the following delimitation of "Europe": reaching across the Ural Mountains, the Ural River, the Caspian Sea, the main Caucasus Divide, the Black Sea, including the Marmara Sea and the Aegean Sea along the divide of the European and Asiatic shelf as well as the European and African tectonic plates (Figure 1). Mascarene Island and the Azores, which politically but not geographically belong to Europe are currently not included, nor are the Selvagenes and the Canary Islands. Our data therefore covers 46 European countries. Speybroeck et al. (2010), in contrast, did not include former republics of the Soviet Union that are partially or completely within Europe (see Suppl. material 2: Table S2.1). Cox and Temple (2009)

are inconsistent in including Greek islands on the Asian shelf but excluding Mediterranean Spanish islands on the African shelf. They further included the Mascarene Island, Selvagenes, and the Canary Islands. Our database is designed in such a way that countries or other geographic entities can be added without a need to change the database structure.

As we wanted to cover European species comprehensively, we also included extra-limital data in the database. We found data for neighbouring countries in Asia (Armenia, Azerbaijan, Georgia, Iran, Israel, Kazakhstan, Kyrgyzstan, Lebanon, Russia, Syria, Tajikistan, Turkey, Turkmenistan, and Uzbekistan) and Africa (Algeria, Morocco) (Figure 1). In addition, case studies from the USA about the invasive European gecko *Hemidactylus turcicus* are included as such data are highly valuable for an assessment of invasion processes of European species. The designation of geographical entities in the database does not imply the expression of any opinion whatsoever on the part of the data compilers concerning the legal status of any country, territory or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries. It is worth noting that in some older references, older geographic names are used that are difficult to match with modern names; in such cases we either retained the old names or used a more inclusive geographic name that encompasses the name in question. The database enables all geographic names to be listed that are used in the database.

Temporal coverage

Currently until mid-2014, life-history trait data were published primarily after the mid-1960s and for many Eastern and southern European taxa primarily in the last 10 years.

Methods

Method step description: We carried out a literature survey in the form of focal species surveys of all European reptiles. A very useful starting point was the Handbook of European Reptiles (in German) (Böhme 1981), as well as French (Arnold and Ovenden 2010) and Spanish (Escarré and Verricard 1981, Salvador and Marco 2009) handbooks and our own extensive collection of life-history publications. These sources already compiled a substantial part of the relevant publications. For species, for which we retrieved no data in above sources, we conducted targeted searches in the ISI web of knowledge, in Google Scholar, and in Google published in English, German, French, and Spanish. We tried to trace any potentially relevant sources cited in the publications found from these searches. Moreover, we presented our project at herpetological conferences to expand our literature sources from experts. However, we only entered data from published literature into the database. The publications that were used to provide data for the database are listed in References. Together, these sources covered

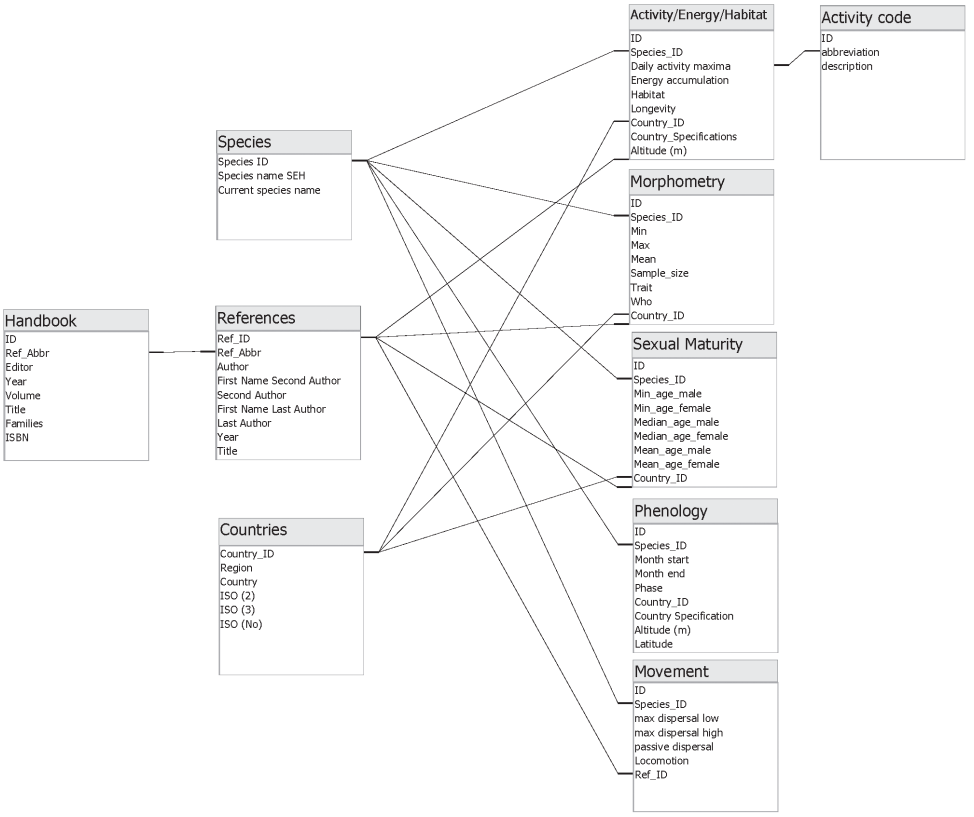

Figure 2. Graphical representation of the database including relationships between the basic tables (*Species; References; Countries*) and the trait tables (*Activity / Energy / Habitat; Sexual Maturity; Phenology; Movement; Morphometry*).

all European reptile species except a few recently described taxa, such as *Dalmatolacerta montenegrina*, for which no life-history data have been published.

Study extent description: All European reptile species are covered in the database without accounting for temporal restrictions as to when the study was conducted.

Sampling description: Before starting the literature search, we decided upon a database structure (Figure 2, described below) and the main topics to be covered. The main topics selected were activity and energy traits, phenological traits, movement/dispersal traits, age at sexual maturity, and morphometry. The literature was searched using specific key words linked to these topics. Detailed definitions of the categories are given below.

Quality control description: All data entries were checked by at least one person other than the one who entered the data. This check also included a plausibility check of the original data. We did not include any data in the database that we could not allocate with certainty to the categories used by us or that were ambiguous in terms of the entity to which they applied.

Dataset descriptions

Our database comprises two sections: basic information and actual trait data. In the basic section, general information about taxonomy, references, and countries is stored. The trait data section is divided into the following: *Activity / Energy / Habitat; Phenology; Sexual Maturity; Movement; and Morphometry*.

Object name: Trait database of reptile life histories
Character encoding: UTF-16
Format name: Microsoft Access Database
Formatversion: Microsoft® Access® 2010 (14.0.7104.5000) SP2 MSO (14.0.7116.5000) as part of Microsoft Office Professional Plus 2010
Distribution: http://scales.ckff.si/scaletool/?menu=6&submenu=0 and http://dx.doi.org/10.5061/dryad.hb4ht
Publication date: 2014–01–21 and 2014–12–08, respectively
Language: English
Licenses of use: Data have been made available under the Creative Commons CC-Zero Waiver: http://creativecommons.org/publicdomain/zero/1.0/. Thus, the data can be freely used for non-commercial purposes provided the source is acknowledged. See Creative Commons for more details of the conditions of usage.

Metadata descriptions

Our relational database is divided into a basic section and the actual trait section (Figure 2). The basic section comprises three tables: *Species*, which lists all 144 European reptile species that we recognised (see the section on taxonomic coverage); *References*, listing all published sources for data extraction (166 in total); *Countries*, listing 46 European, 14 Asian, and 2 African countries and the USA, which is where reptile trait data stem from including their ISO 2, ISO 3, and ISO No codes. In addition, we have names for supranational geographic regions, such as the Caucasus or the Mediterranean, for data where it is not clear from the original source to which country they apply.

In the trait data section, five main tables were created according to the five main topics (*Activity / Energy / Habitat; Phenology; Movement; Sexual Maturity; Morphometry*). All tables are provided with species ID, country ID, country specifications (geographic regions within countries if published), altitude (if published), latitude (if published), longitude (if published), and reference ID so that each data point can be tracked correctly. The definitions and contents of the five tables are described in the following. The words in italics stand for column headings. Capital letters are used for the five main tables.

Activity / Energy / Habitat: Data about *daily activity* describe activity peaks during the day including activity switches within the year. These activity patterns were defined as ten different categories: (1) cn: crepuscular/nocturnal; (2) dn: active the entire

day, no circadian rhythm (diurno-nocturnal); (3) tn: nocturnal, but thermoregulation during the day possible; (4) hu: humidity dependent, no circadian rhythm; (5) 1: one activity peak during the day throughout the year (unimodal); (6) 2: two activity peaks during the day throughout the year (bimodal); (7) as1a: activity shift: summer: one peak during dusk or night (crepuscular or nocturnal), spring/autumn one peak during the day (diurnal) [it is possible that species show bimodal activity between the switch diurnal to nocturnal]; (8) as1b: activity shift: one peak during the day throughout the year, shifted to the morning during the summer; (9) as2a: activity shift: in summer two peaks during the day, spring/autumn: one peak during the day but diurnal throughout the year; (10) as2b: activity shift: summer: one peak during dusk or night (crepuscular/nocturnal), spring/autumn: two peaks during the day (morning/afternoon).

Data about *energy accumulation* denote when species accumulate energy for reproduction (i.e., spring, summer, autumn, or from the previous year – text strings). Moreover, their *habitat* (free text string using general habitat descriptions) and their maximum *longevity* (in years) were listed.

Phenology: Phenological traits refer to four *phases*: the first and second breeding season, aestivation, and hibernation. Each phase is specified by a specific *start* and *end month*. If a publication mentioned a range for the start or end month for a particular area, we used the first month mentioned as the start month and the last month mentioned as the end month for the breeding seasons (to specify the maximum duration available for breeding). For hibernation, in contrast, we used the last month to specify the start month and the first month to designate the end month; thus hibernation data allow a calculation of the maximum time (in months) available for activity.

Movement: Data on movement cover true dispersal, home range movement, and migration because most references do not sufficiently differentiate between these processes. However, if data were sufficiently explicit, we solely used dispersal data. Movement data larger than 250 m were rounded off to 250 m. The reference time span is not necessarily one year but depends on the study described in the original paper. The data in the database are the highest values given by the reference publication for a specific reference area. If a range of maximum dispersal/movement was given in the reference, we provide the lower value in the column *maximum movement low* and the higher value as *maximum movement high*. If no range was given, data were allocated to the latter. Furthermore, *passive dispersal* provides information about whether a species may be dispersed passively through human activities. In addition we provide information about the type of *locomotion* (e.g. swimmers, climbers, runners, or combinations between them).

Sexual Maturity: Age at sexual maturity (in months) was defined as the *minimum, median*, or *mean age* for *males* respectively *females*. The minimum age refers to the lowest age at sexual maturity provided for a specific reference for a specific country. The median age is the age at which 50% (usually most) individuals reach sexual maturity. Mean age is only given if explicit values were provided by the relevant publication.

Morphometry: In the last section, morphometric data are provided as *minimum*, *maximum*, and *mean* values (depending on the data given in the consulted literature).

If published, a *sample size* was listed. *Traits* were specified as mass, length, width, number, or size. These traits always refer to denoted parts of the population (*Who*), such as females, males, hatchlings, juveniles, eggs, or clutches. This structuring allows a maximum number of possible combinations, while using minimal memory space.

Since our database was built as a relational database, IDs between the basic and the trait tables were linked to each other for fast searches and queries (Figure 2).

Metadata language: English
Date of metadata creation: 2014–09–12
Hierarchy level: Database

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References

Arnold N, Ovenden D (2010) Le guide herpéto, 228 amphibiens et reptiles d'Europe. Delachaux et Niestlé, 290 pp.

Böhme W (1981) Handbuch der Reptilien und Amphibien Europas. Aula-Verlag, Wiesbaden.

Chapin FS, Zavaleta ES, Eviner VT, Naylor RL, Vitousek PM, Reynolds HL, Hooper DU, Lavorel S, Sala OE, Hobbie SE, Mack MC, Díaz S (2000) Consequences of changing biodiversity. Nature 405: 234–242. doi: 10.1038/35012241

Cox NA, Temple HJ (2009) European Red List of Reptiles. Office for Official Publications of the European Communities, Luxembourg, 32 pp.

Deutsch CA, Tewksbury JJ, Huey RB, Sheldon KS, Ghalambor CK, Haak DC, Martin PR (2008) Impacts of climate warming on terrestrial ectotherms across latitude. PNAS 105: 6668–6672. doi: 10.1073/pnas.0709472105

Escarré A, Verricard JR (1981) Saurios y Ofidios. Cuadernos de la Fauna Alicantina I. Diputacion de Alicante.

Gasc JP, Cabela A, Crnobrnja-Isailovic J, Dolmen D, Grossenbacher K, Haffner P, Lescure J, Martens H, Martínez Rica JP, Maurin H, Oliveira ME, Sofianidou TS, Veith M, Zuiderwijk A (2004) Atlas of Amphibians and Reptiles in Europe. Collection Patrimoines Naturels, 29, Societas Europaea Herpetologica, Publications scientifiques du Muséum, Paris, 496 pp. http://www.seh-herpetology.org/Distribution_Atlas/ Reptiles_in_Europe

Glandt D (2014) Liste der Amphibien und Reptilien Europas und der angrenzenden Atlantischen Inseln. Aktualisierte Artenliste zu: Gland D (2010) Taschenlexikon der Amphibien und Reptilien Europas. Alle Arten von den Kanarischen Inseln bis zum Ural. Quelle & Meyer, Wiebelsheim, 634 pp.

Henle K, Davies KF, Kleyer M, Margules C, Settele J (2004) Predictors of species sensitivity to fragmentation. In: Henle K, Lindenmayer DB, Margules CR, Saunders DA, Wissel C (Eds) Species Survival in Fragmented Landscapes: Where to from now? Special Issue Biodiversity Conservation 13: 207–251.

Henle K, Kunin W, Schweiger O, Schmeller DS, Grobelnik V, Matsinos Y, Pantis J, Penev L, Potts SG, Ring I, Similä J, Tzanopoulos J, van den Hove S, Baguette M, Clobert J, Excoffier L, Framstad E, Grodinska-Jurczak M, Lengyel S, Marty P, Moilanen A, Porcher E, Storch D, Steffan-Dewenter I, Sykes MT, Zobel M, Settele J (2010) Securing the conservation of biodiversity across administrative levels and spatial, temporal, and ecological scales. GAIA 19(3): 187–193.

Ilg C, Foeckler F, Deichner O, Henle K (2012) Hydrological gradient and species traits explain gastropod diversity in floodplain grasslands. River Research and Applications 28: 1620–1629. doi: 10.1002/rra.1552

Kahl T, Bauhus J (2014) An index of forest management intensity based on assessment of harvested tree volume, tree species composition and dead wood origin. Nature Conservation 8: 15–27. doi: 10.3897/natureconservation.7.7281

Kearney M, Porter W (2009) Mechanistic niche modelling: combining physiological and spatial data to predict species' ranges. Ecology Letters 12: 334–350. doi: 10.1111/j.1461-0248.2008.01277.x

Keil P, Schweiger O, Kühn I, Kunin WE, Kuussaari M, Settele J, Henle K, Brotons L, Pe'er G, Lengyel S, Moustakas A, Steinicke H and Storch D (2012) Patterns of beta diversity in Europe: the role of climate, land cover and distance across scales. Journal of Biogeography 39: 1473–1486. doi: 10.1111/j.1365-2699.2012.02701.x

Kleyer M (1999) Distribution of plant functional types along gradients of disturbance intensity and resource supply in an agricultural landscape. Journal of Vegetation Science 10: 697–708. doi: 10.2307/3237084

Kuussaari M, Heliölä J, Pöyry J, Saarinen K (2007) Contrasting trends in butterfly species preferring semi-natural grasslands, field margins and forest edges in northern Europe. Journal of Insect Conservation 11: 351–366. doi: 10.1007/s10841-006-9052-7

Mayer W (2013) Kommentierte Lacertiden-Liste für Europa, Afrika, den Nahen Osten inklusive der Arabischen Halbinsel und Asien. L@CERTIDAE 2013: 81–141.

Mertens R, Wermuth H (1960) Die Amphibien und Reptilien Europas (Dritte Liste nach dem Stand vom 1.1.1960). Kramer, Frankfurt, 264 pp.

Novosolov M, Raia P, Meiri S (2013) The island syndrome in lizards. Global Ecology and Biogeography 22: 184–191.

Pe'er G, Tsianou MA, Franz KW, Matsinos GY, Mazaris AD, Storch D, Kopsova L, Verboom J, Baguette M, Stevens VM, Henle K (2014) Toward better application of Minimum Area Requirements in conservation planning. Biological Conservation 170: 92–102. doi: 10.1016/j.biocon.2013.12.011

Pütz S, Groeneveld J, Henle K, Knogge C, Martensen AC, Metz M, Metzger JP, Ribeiro MC, de Paula MD, Huth A (2014) Long-term carbon loss in fragmented neotropical forests. Nature Communications 5, article 5037.

Salvador A, Marco A (2009) Enciclopedia Virtual de los Vertebrados Españoles. Museo Nacional de Ciencias Naturales, Madrid.

Schulte U, Hochkirch A, Lötters S, Rödder D, Schweiger S, Weimann T, Veith M (2012) Cryptic niche conservatism among evolutionary lineages of an invasive lizard. Global Ecology and Biogeography 21: 198–211. doi: 10.1111/j.1466-8238.2011.00665.x

Sillero N, Campos J, Bonardi A, Corti C, Creemers R, Crochet P-A, Isailović JC, Denoël M, Ficetola GF, Gonçalves J, Kuzmin S, Lymberakis P, de Pous P, Rodríguez A, Sindaco R, Speybroeck J, Toxopeus B, Vieites DR, Vences M (2014) Updated distribution and biogeography of amphibians and reptiles of Europe. Amphibia-Reptilia 35: 1–31. doi: 10.1163/15685381-00002935

Sindaco R, Jeremčenko VK (2008) The reptiles of the western Palearctic. 1. Annotated checklist and distributional atlas of the turtles, crocodiles, amphisbaenians and lizards of Europe, North Africa, Middle East and Central Asia. Edizioni Belvedere, Latina, 580 pp.

Sinervo B, Méndez-de-la-Cruz F, Miles DB, Heulin B, Bastiaans E, Cruz MV-S, Lara-Resendiz R, Martínez-Méndez N, Calderón-Espinosa ML, Meza-Lázaro RN, Gadsden H, Avila LJ, Morando M, De la Riva IJ, Sepulveda PV, Rocha CFD, Ibargüengoytía N, Puntriano CA, Massot M, Lepetz V, Oksanen TA, Chapple DG, Bauer AM, Branch WR, Clobert J, Sites Jr. JW (2010) Erosion of lizard diversity by climate change and altered thermal niches. Science 328: 894–899. doi: 10.1126/science.1184695

Speybroeck J, Beukema W, Crochet P-A (2010) A tentative species list of the European herpetofauna (Amphibia and Reptilia) – an update. Zootaxa 2492: 1–27.

Stevens VM, Turlure C, Baguette M (2010) A meta-analysis of dispersal in butterflies. Biological Reviews 83: 625–642.

Stevens VM, Trochet A, Blanchet S, Moulherat S, Clobert J, Baguette M (2013) Dispersal syndroms and the use of life-histories to predict dispersal. Evolutionary Applications 6: 630–642. doi: 10.1111/eva.12049

Uetz P, Hošek J (2014) The Reptile Database; http://www.reptile-database.org, accessed Aug 7, 2014.

References used for the compilation of data in the database.

Aleksic I, Ljubisavljevic K (2001) Reproductive cycle in the common wall lizards (*Podarcis muralis*) from Belgrade. Archives of Biological Science Belgrade 2000: 73–81.

Amat F, Lloente GA, Carretero MA (2000) Reproductive cycle of the sand lizard (*Lacerta agilis*) in its southwestern range. Amphibia-Reptilia 21: 463–476. doi: 10.1163/156853-800300059340

Arakelyan M (2002) The study of age, growth, and longevity in the triploid hybrids of rock lizards of the genus *Darevskia* in Armenia. Russian Journal of Herpetology 9: 63–68.

Arnold N, Ovenden D (2010) Le guide herpéto, 228 amphibiens et reptiles d'Europe. Delachaux et Niestlé.

Arntzen JW, Sa-Sousa P (2007) Morphological and genetical differentiation of lizards (*Podarcis bocagei* and *Podarcis hispanica*) in the Ria de Arosa Archipelago (Galicia, Spain) resulting from vicariance and ocassional dispersal. In: Renema W (Ed.) Biogeography, Time and Place: Distributions, Barriers and Islands. Springer Verlag, 365–401.

Arribas, OJ (1994) Diagnosis and redescription of *Lacerta bonnali* (Lantz, 1927). Bolletino del Museo Regionale di Scienze Naturali (Torino) 12: 357–366.

Arribas OJ (1996) Taxonomic revision of the Iberian 'Archaeolacertae' I.: A new interpretation of the geographical variation of *'Lacerta' monticola* Boulenger, 1905 and *'Lacerta' cyreni* Müller & Hellmich, 1937. Herpetozoa 9: 31–56.

Arribas OJ (2004) Characteristics of the reproductive biology of *Iberolacerta aurelioi* (Arribas, 1994) (Squamata: Sauria: Lacertidae). Herpetozoa 17: 3–18.

Arribas OJ (2009) Lagartija pirenaica- *Iberolacerta bonnali*. In: Salvador, A, Marco, A (Eds) Enciclopedia Virtual de los Vertebrados Españoles. Museo Nacional de Ciencias Naturales Madrid.

Arribas OJ (2010) Activity, microhabitat selection and thermal behavior of the Pyrenean rock lizards *Iberolacerta aranica* (Arribas, 1993), *I. aurelioi* (Arribas, 1994) and *I. bonnali* (Lantz, 1927). Herpetozoa 23: 3–23.

Arribas OJ, Galán P (2005) Reproductive characteristics of the Pyrenean high-mountain lizards: *Iberolacerta aranica* (Arribas, 1993), *I. aurelioi* (Arribas, 1994) and *I. bonnali* (Lantz, 1927). Animal Biology 55: 163–190. doi: 10.1163/1570756053993505

Barbault R, Mou Y-P (1988) Population dynamics of the common wall lizard, *Podarcis muralis*, in Southwestern France. Herpetologica 44: 38–47.

Bauwens D, Diaz-Uriarte R (1997) Covariation of life-history traits in lacertid lizards: A comparative study. The American Naturalist 149: 91–111. doi: 10.1086/285980

Bauwens D, Verheyen RF (1985) The timing of reproduction in the lizard *Lacerta vivipara*. Differences between individual females. Journal of Herpetology 19: 353–364. doi: 10.2307/1564263

Bauwens D, Verheyen RF (1987) Variation of reproductive traits in a population of the lizard *Lacerta vivipara*. Holoarctic Ecology 10: 120–127.

Bender C, Hildebrandt H, Schmidt-Loske K, Grimm V, Wissel C, Henle K (1996) Consolidation of vineyards, mitigations, and survival of the common wall lizard (*Podarcis muralis*) in isolated habitat fragments. In: Settele J, Margules CR, Poschold P, Henle K (Eds) Species Survival in Fragmented Landscapes. Kluwer, Dordrecht, 248–261. doi: 10.1007/978-94-009-0343-2_30

Bergman J (1989) Neues über *Podarcis taurica* (Pallas, 1989) in der asiatischen Turkei. Salamandra 26: 85–86.

Berglind SA (2000) Demography and management of relict sand lizard *Lacerta agilis* populations on the edge of extinction. Ecological Bulletins 48: 123–142.

Blanke I (2010) Die Zauneidechse: zwischen Licht und Schatten. Beiheft der Zeitschrift für Feldherpetologie 7: 1–176.

Böhme W (1981) Handbuch der Reptilien und Amphibien Europas. Band 1. Echsen (Sauria) I. Aula-Verlag, Wiesbaden.

Böhme W (1984) Handbuch der Reptilien und Amphibien Europas. Band 2/I. Echsen (Sauria) II (Lacerta). Aula-Verlag, Wiesbaden.

Böhme W (1986) Handbuch der Reptilien und Amphibien Europas. Band 2/II. Echsen (Sauria) III (Podarcis). Aula-Verlag, Wiesbaden.

Böhme W (1995) Handbuch der Reptilien und Amphibien Europas. Band 3/1. Schlangen (Serpentes) I (Typhlopidae, Boidae, Colubridae 1). Aula-Verlag, Wiesbaden.

Böhme W (1999) Handbuch der Reptilien und Amphibien Europas. Band 3/2A. Schlangen (Serpentes) II (Colubridae 2 (Boidinae, Natricinae)). Aula-Verlag, Wiesbaden.

Böhme W, Fritz U (2001) Handbuch der Reptilien und Amphibien Europas. Band 3/3A. Schildkröten (Testudines) I (Bataguridae, Testudinidae, Emydidae). Aula-Verlag, Wiesbaden.

Böhme W, Fritz U (2005) Handbuch der Reptilien und Amphibien Europas. Band 3/3B. Schildkröten (Testudines) II (Cheloniidae, Dermochelyidae, Fossile Schildkröten Europas). Aula-Verlag, Wiesbaden.

Böhme W, Joger U, Stümpel N (2005) Handbuch der Reptilien und Amphibien Europas. Band 3/2B. Schlangen (Serpentes) III (Viperidae). Aula-Verlag, Wiesbaden.

Braña F (1996) Sexual dimorphism in lacertid lizards: Male head increase vs female abdomen increase? Oikos 75: 511–523. doi: 10.2307/3545893

Braña F, Arrayago MJ, Bea A, Barahona A (1990) Ciclo reproductor y de cuerpos grasos en los machos de *Lacerta monticola cantabrica*. Comparacion entre dos poblaciones situadas a diferente altitud. Amphibia-Reptilia 11: 41–52. doi: 10.1163/156853890X00302

Braña F, Bea A, Arrayago MJ (1991) Egg retention in lacertid lizards: Relationships with reproductive ecology and the evolution of viviparity. Herpetologica 47: 218–226.

Braña F, Gonzalez F, Barahona A (1992) Relationship between ovarian and fat body weights during votellogenesis for three species of lacertid lizards. Journal of Herpetology 26: 515–518. doi: 10.2307/1565137

Braña F, Ji X (2000) Influence of incubation temperature on morphology, locomotor performance, and early growth of hatchling wall lizards (*Podarcis muralis*). Journal of Experimental Zoology 286: 422–433. doi: 10.1002/(SICI)1097-010X(20000301)286:4<422::AID-JEZ10>3.0.CO;2-D

Bressi N (2004) *Algyroides nigropunctatus nigropunctatus* in Italy: notes on ecology, habitat selection and conservation (Reptilia, Lacertidae). Italian Journal of Zoology 71: 113–116. doi: 10.1080/11250003.2004.9525546

Busack SD (1986) Taxonomic implications of biochemical and morphological differentiation in spanish and moroccan populations of the three-toed skinks, *Chalcides chalcides* (Lacertilia, Scincidae). Herpetologica 42: 230–236.

Busack SD, Klostermann LL (1987) Reproduction in a Spanish population of *Acanthodactylus erythrurus*. Annals of Carnegie Museum 56: 97–102.

Caetano MH, Castanet J, Crespo EG (1986) Estimation a l'aide de la squelettochronologie de l'age de *Podarcis hispanica*, (Steindachner, 1870). Sauria, Lacertidae provenant de'une population portugaise. Revue suisse Zoology 93: 117–127.

Carretero MA (1994) Algunes dades morfometriques de *Psammodromus hispanicus* al Prat de Llobregat. Spartina 1: 13–19.

Carretero MA, Llorente GA (1991) Reproducción de *Psammodromus hispanicus* en una arenal costero del nordeste ibérico. Amphibia-Reptilia 12: 395–408. doi: 10.1163/156853891X00040

Carretero MA, Llorente GA (1995) Reproduction of *Acanthodactylus erythrurus* in its nothern boundary. Russian Journal of Herpetology 2: 10–17.

Carretero MA, Llorente GA, Santos X (1995) Características reproductoras de una población introducida de *Podarcis pityusensis*. Revista Espanola de Herpetologica 1995: 93–102.

Castilla AM, Barbadillo LJ, Bauwens D (1992) Annual variation in reproductive traits in the lizard *Acanthodactylus erythrurus*. Canadian Journal of Zoology 70: 395–402. doi: 10.1139/z92-059

Castilla AM, Bauwens D (2000) Reproductive characteristics of the island lacertid lizard *Podarcis lilfordi*. Journal of Herpetology 34: 390–396. doi: 10.2307/1565362

Chondropoulos BP, Lykakis J (1983) Ecology of the Balkan wall lizard, *Podarcis taurica ionica* (Sauria:Lacertidae) from Greece. Copeia 1983(4): 991–1001. doi: 10.2307/1445101

Cirer AM (1980) Descripció de deus subspécies noves de *Podarcis pityusensis*. Bulletin of the Institució Catalana d'Història Natural 45: 121–126.

Corti C, Lo Cascia P (2002) The Lizards of Italy and Adjacent Areas. Chimaira, Frankfurt/Main.

Crnobrnja-Isailovic J, Aleksic I (2004) Clutch size in two Central Balkan populations of European common lizard *Lacerta vivipara*. Biota 5: 5–10.

Cuadrado M, Loman J (1999) The effect of age and size on reproductive timing in female *Chamaeleo chamaeleon*. Journal of Herpetology 33: 6–11. doi: 10.2307/1565536

Darevsky IS (1966) Natural parthenogenesis in a polymorphic group of Caucasian rock lizards related to *Lacerta saxicola* Eversmann. Journal of the Ohio Herpetological Society 5: 115–152. doi: 10.2307/1562588

Darevsky IS (1978) Rock Lizards of the Caucasus. Smithonian Institution and National Science Foundation & Indian National Scientific Documentation, Washington & New Dehli.

Dexel R (1986) Zur Ökologie der Mauereidechse *Podarcis muralis* (Laurenti, 1768) (Sauria: Lacertidae) an ihrer nördlichen Arealgrenze 1. Salamandra 22: 259–271.

Diaz JA, Iareta P, Verdu-Ricoy J (2012) Intraspecific variation of reproductive traits in a Mediterranean lizard: Clutch, population, and lineage effects. Evolutionary Biology 39: 106–115. doi: 10.1007/s11692-011-9144-5

Eckstut ME, Lemons ER, Server DM (2009) Annual dynamics of sperm production and storage in the Mediterranean gecko, *Hemidactylus turcius*, in the southeastern United States. Amphibia-Reptilia 30: 45–56. doi: 10.1163/156853809787392649

Eikhorst W, Eikhorst R, Rykena S (1979) Beobachtungen an der spanischen Kieleidechse, *Algyroides marchi* Valverde. Salamandra 15: 254–263.

Elbing K (2001) Die Smaragdeidechsen: zwei (un)gleiche Schwestern. Beiheft zur Zeitschrift für Feldherpetologie 3: 1–143.

Escarré A, Verricard JR (1981) Sarios y Ofidios. In: Cuadernos de la Fauna Alicantina I. Diputacion de Alicante.

Flatt T, Dummermuth S (1993) Zur Kenntnis der Aspis- oder Juraviper *Vipera aspis aspis* (L., 1758) im Kanton Solothurn. Mitteilungen der Naturforschenden Gesellschaft Kanton Solothurn 36: 75–102.

Frankenberg E (1978) Interspecific and seasonal variation of daily activity in gekkonid lizards (Reptilia, Lacertilia). Journal of Herpetology 12: 505–519. doi: 10.2307/1563356

Franzen M, Bussmann M, Kordges T (2008) Die Amphibien und Reptilien der Südwest-Türkei. Beiheft der Zeitschrift für Feldherpetologie 14: 1–328.

Freundt R (2012) Drittgelege-Nachweis und weitere Beobachtungen an einer individuenreichen Population der Zauneidechse (*Lacerta agilis*) im Niederrheinischen Tiefland (NRW). Zeitschrift für Feldherpetology 19: 175–184.

Gabriot M, Lopéz P, Martin J (2012) Interpopulational variation in chemosensory responses to selected steroids from femoral secretions of male lizards, *Podarcis hispanica*, mirrors population differences in chemical signs. Chemoecology 22: 65–73. doi: 10.1007/s00049-011-0100-8

Galán P (1984) Estudio sobre la biometria, diseno y coloracion de *Lacerta schreiberi*, Bedriaga, 1978. (Sauria, Lacertidae). Alytes 2: 25–54.

Galán P (1996) Reproductive and fat body cycles of the lacertid lizard *Podarcis bocagei*. Herpetological Journal 6: 20–25.

Galán P (1997) Reproductive ecology of the lacertid lizard *Podards bocagei*. Ecography 20: 197–209. doi: 10.1111/j.1600-0587.1997.tb00362.x

Galán P (1999) Demography and population dynamics of the lacertid lizard *Podarcis bocagei* in north-west Spain. Journal of Zoology London 249: 203–218. doi: 10.1111/j.1469-7998.1999.tb00759.x

Galán P (2003a) Female reproductive characteristics of the viviparous skink *Chalcides bedriagai pistaciae* (Reptilia, Squamata, Scincidae) from an Atlantic beach in north-west Spain. Amphibia-Reptilia 24: 79–85.

Galán P (2003b) Reproductive characteristics of an insular population of the lizard *Podarcis hispanica* from northwest Spain (Cies Islands, Galicia). Copeia 2003: 657–665. doi: 10.1643/CH-02-235R1

Galán P (2004) Structure of a population of the lizard *Podarcis bocagei* in Northwest Spain: variations in age distribution, size distribution and sex ratio. Animal Biology 54: 57–75. doi: 10.1163/157075604323010051

Galán P (2007) Datos sobre el crecimiento, madurez y dimorfismo sexual en una población natural de lución (*Anguis fragilis*) en el Noroeste de la Península Ibérica. Munibe 25: 164–169.

Galán P (2008a) Efecto de la planta invasora *Carpobrotus edulis* sobre la densidad del eslizón tridáctilo (*Chalcides striatus*) en una localidad costera de Galicia. Boletín de la Asociación Herpetológica Española 19: 117–121.

Galán P (2008b) Ontogenetic and sexual variation in the coloration of the lacertid lizards *Iberolacerta monticola* and *Podarcis bocagei*. Do the females prefer the greener males? Animal Biology 58: 173–198. doi: 10.1163/157075608X328026

Galán P (2009) Ecología de la reproducción de los saurios ibéricos. Boletin de la Asociacion Herpetologica Española 20: 1–34.

Galán P, Vila M, Remon N (2007) Caracterizacion de las poblaciones de *Iberolacerta monticola* en el Noroeste iberico mediante la combinacion de datos morfologicos, ecologicos y geneticos. Munibe (Suplemento/gehigarria) 25: 34–43.

Gil MJ, Guerrero F, Pérez-Mellado V (1994) Clutch size and reproductive frequency of *Blanus cinereus* in central Spain. Acta Biologica Cracoviensia 36: 37–40.

Glandt D (2001) Die Waldeidechse: unscheinbar - anpassungsfähig – erfolgreich. Beiheft der Zeitschrift für Feldherpetologie 2: 1–111.

Gonzáles de la Vega F (1988) Anfibios y reptiles de la provincia de Huelva. Eds Ertisa Huelva.

Guarino FM, Di Gui I, Sindaco R (2010) Age and growth of the sand lizards (*Lacerta agilis*) from a high Alpine population of north-western Italy. Acta Herpetologica 5: 23–29.

Guillaume CP, Geniez P (1986) Descriptin d'une sous-espece de *Podarcis hispanica* (Sauria, Lacertidae): *Podarcis hispanica cebennensis*. Bulletin de la Société Herpétologique de France 39: 1–5.

Günther R (1996) Waldeidechse - *Lacerta vivipara* Jacquin, 1787. In: Günther R (Ed) Die Amphibien und Reptilien Deutschlands. Gustav Fischer, Jena.

Gvozdik L (2000) Seasonal activity, sex ratio, and abundance in a population of *Lacerta agilis* Linneaus, 1758 from Czech Republic. Herpetozoa 13: 165–169.

Hailey A, Rose CA, Puldorf E (1987) Food consumption, thermoregulation and ecology of the skink *Chalcides bedriagai*. Herpetological Journal 1: 144 – 153.

Henle K (1988) Dynamics and ecology of three Yugoslavian populations of the Italian wall lizard (*Podarcis sicula campestris* De Betta) (Reptilia: Lacertidae). Zoologischer Anzeiger 220: 33–48.

Heulin B (1985) Maturité sexuelle et âge à la première reproduction dans une population de plaine de *Lacerta vivipara*. Canadian Journal of Zoology 63: 1773–1777. doi: 10.1139/z85-266

Heulin B, Osenegg K, Michel D (1994) Survie et incubation des ceufs dans deux populations ovipares de *Lacerta vivipara*. Amphibia-Reptilia 15: 199–219. doi: 10.1163/156853894X00308

Hofmann S (2004) Populationsbiologischen Untersuchungen an der Waldeidechse, *Zootoca vivipara* (Jacquin, 1787) in Sachsen-Anhalt und West Sachsen. Dissertation Martin-Luther-Universitat Halle-Wittenberg.

Horvathova T, Balaz M, Jandzik D (2013) Reproduction and morphology of the common lizard (*Zootoca vivipara*) from montane populations in Slovakia. Zoological Science 30: 92–98. doi: 10.2108/zsj.30.92

Hraoui-Bloquet S, Sadek R, Sabeh MA (1999) The male sexual cycle of *Lacerta media* Lantz and Cyren in Mount Lebanon compared with that of *Lacerta laevis* Gray. Bulletin de la Société Herpétologique de France 92: 5–17.

Ilgaz C, Baran I (2001) Reproduction biology of the marine turtle populations in Northern Karpaz (Cyprus) and Dalyan (Turkey). Zoology of the Middle East 24: 35–44. doi: 10.1080/09397140.2001.10637884

Ji X, Braña F (2000) Among clutch variation in reproductive output and egg size in the wall lizard (*Podarcis muralis*) from a low land population of Nothern Spain. Journal of Herpetology 34: 54–60. doi: 10.2307/1565238

Käsewieter D (2002) Ökologische Untersuchungen an der Schlingnatter (*Coronella austriaca* Laurenti, 1768). Dissertation, University of Bayreuth.

Klewen R (1988) Verbreitung, Ökologie und Schutz von *Lacerta agilis* im Ballungsraum Duisburg/Oberhausen. Mertensiella 1: 178–194.

Lapini L, Richard J, Dall'Asta A (1993) Distribution and ecology of *Lacerta horvathi* Méhély, 1904 (Reptilia, Lacertidae) in north-eastern Italy. gortania – Atti Museo Friulano di Storia Naturale 14: 213–230.

Lelievre H, Blouin-Demers G, Lourdais O (2011) Contrasted thermal preferences translate into divergences in habitat use and realized performance in two sympatric snakes. Journal of Zoology 284: 265–275. doi: 10.1111/j.1469-7998.2011.00802.x

Locey KJ, Stone PA (2006) Factors affecting range expansion in the introduced Mediterranean gecko, *Hemidactylus turcicus*. Journal of Herpetology 40: 526–530. doi: 10.1670/0022-1511(2006)40[526:FAREIT]2.0.CO;2

Luís C, Rebelo R, Crespo EG (2004) Age structure in *Lacerta schreiberi* from Portugal. Amphibia-Reptilia 25: 336–343.

Malkmus R (1982) Beitrag zur Verbreitung der Amphibien und Reptilien in Portugal. Salamandra 18: 218–299.

Maragou P, Valakos ED, Chondropoulos BP (1997) Comparative ecology of two sympatric lizard species, *Lacerta graeca* and *Podarcis peloponnesiaca* endemic to Peloponnisos (Greece). In: Böhme W, Bischoff W, Ziegler T (Eds) Herpetologia Bonnensis. SEH, Bonn, 265–271.

Maragou P, Chrondropoulos BP, Valakos ED (1999) Comparative data on reproduction in *Podarcis erhardii*, *Podarcis peloponnesiaca*, and *Podarcis taurica* (Reptilia, Sauria, Lacertidae). Israel Journal of Zoology 45: 487–496.

Marco A, Pérez-Mellado V (1998) Influence of clutch date on egg and hatchling sizes in the annual clutch of *Lacerta schreiberi* (Sauria, Lacertidae). Copeia 1998(1): 145–150. doi: 10.2307/1447710

Marco A, Pérez-Mellado V, Gil-Costa MJ (1994) Reproductive strategy in a montane population of the lizard *Lacerta schreiberi* (Sauria: Lacertidae). Herpetological Journal 4: 49–55.

Marco A, Diaz-Paniagua C, Hidalgo-Vila J (2004) Influence of egg aggregation and soil moisture on incubation of flexible-shelled lacertid lizard eggs. Canadian Journal of Zoology 82: 60. doi: 10.1139/z03-209

Martin J (2009) Lagartija Serrana- *Iberolacerta monticola*. In: Salvador A, Marco A (Eds) Enciclopedia Virtual de los Vertebrados Españoles. Museo Nacional de Ciencias Naturales Madrid.

Martin J, López P, Salvador A (1990) Field body temperatures of the amphisbaenid lizard *Blanus cinereus*. Amphibia-Reptilia 11: 87–96. doi: 10.1163/156853890X00492

Martin J, Salvador A (1993) Tail loss reduces mating success in the Iberian rock-lizard, *Lacerta monticola*. Behavioural Ecology and Sociobiology 32: 185–189. doi: 10.1007/BF00173776

Martin J, Salvador A (1995a) Microhabitat selection by the Iberian rock lizard *Lacerta monticola*: Effects on density and spatial distribution of individuals. Biological Conservation 79: 303–307. doi: 10.1016/0006-3207(95)00110-7

Martin J, Salvador A (1995b) Effects of tail loss on activity patterns of rock-lizard, *Lacerta monticola*. Copeia 1995(4): 984–988. doi: 10.2307/1447052

Martínez-Rica JP (1974) Contribucion al estudio de la Biologia de los geconidos ibericos (Rept., Sauria). Publicaciones del Centro Pirenaico de Biologia Experimental. 5: 1–291.

Martin-Vallejo J, Garcias-Fernandez J, Pérez-Mellado V (1995) Habitat selection and thermal ecology of the sympatric lizards *Podarcis muralis* and *Podarcis hispanica* in a mountain region of central Spain. Herpetological Journal 5: 181–188.

Meeske, M (2006) Die Europäische Sumpfschildkröte am nördlichen Rand ihrer Verbreitung in Litauen. Beiheft der Zeitschrift für Feldherpetologie 11: 1–160.

Mitchell JC, Pague, CA (1990) Body size, reproductive variation, and growth in the slider turtle at the northeastern edge of its range. In Gibbons JW (Ed) Life History and Ecology of the Slider Turtle. Smithonian Inst. Press, Washington, 146–151.

Mole S (2008) An Investigation into the Effects of the Western Green Lizard (*Lacerta bilineata*) and the Common Wall Lizard (*Podarcis muralis*) Introduced onto Boscombe Cliffs, Dorset, U.K. Bachelor Thesis, Sparsholt College, Great Britain.

Morina-Borja M, Rodríguez-Domínguez MA (2004) Evolution of biometric and life-history traits in lizards (*Gallotia*) from the Canary Islands. Journal of Zoological Systematics and Evolutionary Research 42: 44–53. doi: 10.1046/j.0947-5745.2003.00239.x

Nollert A (1983) Einige Bemerkungen zur Taurischen Eidechse, *Podarcis taurica taurica* (Pallas), in Südostbulgarien. Herpetofauna 25: 26–29.

Olsson M, Shine R (1997a) The seasonal timing of oviposition in sand lizards (*Lacerta agilis*): why early clutches are better. Journal of Evolutionary Biology 10: 369–381. doi: 10.1007/s000360050030

Olsson M, Shine R (1997b) The limits to reproductive output: offspring size versus number in the Sand Lizard (*Lacerta agilis*). The American Naturalist 149: 179–188. doi: 10.1086/285985

Orlova VF, Kuranova VN, Bulakhova (2003) Some aspects of reproductive biology of *Zootoca vivipara* (Jacquin, 1787) in the Asian part of its area. In: Ananjeva N, Tsineko O (Eds). Herpetologia Petropolitana, 201–204.

Ouboter PE (1981) The ecology of island-lizard *Podarcis sicula salfii*: Correlation of microdistribution with vegetation coverage, thermal environment and food size. Amphibia-Reptilia 2: 243–257. doi: 10.1163/156853881X00078

Pellitteri-Rosa D, Sacchi R, Pupin F (2012) Testing the ability to store sperm: an experimental manipulation of mating opportunities in the common wall lizard, *Podarcis muralis*. Acta Herpetologica 7: 111–118.

Perera A, Pérez-Mellado V, Harris DJ (2006) Variation between populations in the diet of the Mediterranean lizard *Lacerta perspicillata*. Herpetological Journal 16: 107–113.

Perez Quintero JC (1988) Biometria y reproduccion del eslizon tridactilo, *Chalcides chalcides striatus* (Cuvier), en las Marismas del Odiel (Huelva). Revista Esp. Herpetologia 3: 15–27.

Pérez-Mellado V, Hernández-Estévez JA, Garcá-Díez T (2008) Populatin density in *Podarcis lilfordi* (Squamata, Lacertidae), a lizard species endemic to small islets in the Balearic Islands (Spain). Amphibia-Reptilia 29: 46–60. doi: 10.1163/156853808783431587

Peters G (1970) Studien zur Taxonomie, Verbreitung und Ökologie der Smaragdeidechsen IV. Zur Ökologie und Geschichte der Populationen von *Lacerta v. viridis* (Laurenti) im Mitteleuropäischen Flachland. Beiträge zur Tierwelt der Mark 7: 49–119.

Picariello O, Cicaria G, Angelini F (1989) The annual cycle of oviduct in *Tarentola m. mauritanica* L. (Reptilia, Gekkonidae). Amphibia-Reptilia 10: 371–386. doi: 10.1163/156853889X00025

Pleguezuelos JM, Feriche M (1998) Reproductive biology of the secretive Mediterranean colubrid *Macroprotodon cucullatus* in the southern Iberian Peninsula. Herpetological Journal 8:195–200.

Pollo CJ, Pérez-Mellado V (1990) Biologia reproductora de tres especies Mediterraneas de Lacertidae. Mediterranea Ser. Biol. 12: 149 – 160.

Pollo CJ (2009a) Eslizón ibérico – *Chalcides bedriagai* Boscá, 1880. In: Salvador A, Marco A (Eds) Enciclopedia Virtual de los Vertebrados Españoles. Museo Nacional de Ciencias Naturales Madrid.

Pollo CJ (2009b) Eslizón tridáctilo ibérico – *Chalcides striatus*. In: Salvador A, Marco A (Eds). Enciclopedia Virtual de los Vertebrados Españoles. Museo Nacional de Ciencias Naturales Madrid.

Polovic L, Pesic V, Ljubisavljevic K, Cadenovic N (2013) Preliminary data on the reproductive characteristics and diet in an insular population of the lacertid lizard *Algyroides nigropunctatus*. North-Western Journal of Zoology 9 : 201–205.

Pottier G (2005) Découverte du Lézard ocellé *Lacerta lepida* Daudin, 1802 (Reptilia, Lacertidae) et confirmation de l'existence du Seps strié *Chalcides striatus* (Cuvier, 1829) (Reptilia, Scincidae) dans les Petites Pyrénées. Bulletin de la Société. Herpétologique de France 113–114: 29–43.

Punzo F (2001) The Mediterranean gecko, *Hemidactylus turcicus*: life in an urban landscape. Florida Scientist 64: 56–66.

Rasilla D, Pérez-Mellado V (2004) Density dependence of the survival in the Iberian wall lizard (*Podarcis hispanica*). In: Perez-Mellado V, Riera N, Perera A (Eds) The Biology of Lacertid Lizards. Evolutionary and Ecological Perspectives. Institut Menorqui d'Estudis, 177–200.

Rodriguez-Diaz T, Braña F (2012) Altitudinal variation in egg retention and rates of embryonic development in oviparous *Zootoca vivipara* fits predictions from the cold-climate model on the evolution of viviparity. Journal of Evolutionary Biology 25: 1877–1887. doi: 10.1111/j.1420-9101.2012.02575.x

Rodriguez-Ruiz FJ (1976) Datos sobre la sistemática de los lacértidos de la isla de Formentera e islotes adyacentes. Boletín de la Sociedad de Historia Natural de Baleares 21: 47–75.

Roig JM, Carretero MA, Llorente GA (2000) Reproductive cycle in a Pyrenean oviparous population of the common lizard (*Zootoca vivipara*). Netherlands Journal of Zoology 50: 15–27.

Rúa M, Galán P (2003) Reproductive characteristics of a lowland population of an alpine lizard: *Lacerta monticola* (Squamata, Lacertidae) in north-west Spain. Animal Biology 53: 347–366. doi: 10.1163/157075603322556265

Rugiero L (1997) On the ecology and phenology of *Chalcides chalcides* in central Italy. Herpetozoa 10: 81–84.

Rugiero L (1995) Winter activity of a common wall lizard (*Podarcis muralis*) population in central Italy. Russian Journal of Herpetology 2: 148–152.

Ryberg K, Olsson M, Wapstra E, Madsen T, Ujvari B (2004) Offspring-driven local dispersal in female sand lizards (*Lacerta agilis*). Journal of Evolutionary Biology 17: 1215–1220. doi: 10.1111/j.1420-9101.2004.00798.x

Rykena S (1987) Egg incubation time and nothern distribution boundary in green lizard species (*Lacerta* s. str). In: van Gelder JJ, Strijbosch H, Bergers PJM (Eds) Proceedings of the 4th Ordinary General Meeting of the Societas. Europaea Herpetologica. – Faculty of Sciences Nijmegen, 339–342.

Saint Girons H, Castanet J, Bradshaw SD (1989) Demographie comparee de deux populations francaises de *Lacerta viridis* (Laurenti, 1768). Revue d'Écologie (Terre Vie) 44: 361–386.

Salvador A (1978) Materiales para una 'Herpetofauna Balearica' 5. Las salamanquesas y tortugas del archipielago de Cabrera. Doñana, Acta Vertebrata 5: 5–17.

Salvador A, Diaz JA, Veiga JP (2007) Correlates of reproductive success in males lizards of the alpine species *Iberolacerta cyreni*. Behavioral Ecology 19: 169–176. doi: 10.1093/beheco/arm118

Sapovaliv P (1987) Morphometry and variability of morphological characters in *Lacerta viridis* (Laurenti, 1768). Fauna Bohemiae Septentrionalis 12: 75–101.

Sa-Sousa P, Vicente L, Crespo EG (2002) Morphological variability of *Podarcis hispanica* (Sauria:Lacertidae) in Portugal. Amphibia-Reptilia 23: 55–69. doi: 10.1163/156853802320877627

Saveliev SS, Bulakhova NA, Kuranova VN (2006) Reproductive activity of *Lacerta agilis* and *Zootoca vivipara* (Reptilia-Sauria) in western Siberia. In: Vences M, Kohler J, Ziegler T, Böhme W (Eds) Herpetologia Bonnensis II, 133–137.

Schneeweiß N (2001) Aspekte der Entwicklung und des Ausbreitungsverhaltens von Smaragdeidechsen in einem Ansiedlungsvesuch in Brandenburg. Mertensiella 12: 229–240.

Schneeweiß N (2012) Missglückter Versuch einer Ansiedlung von *Lacerta viridis* in Nordostdeutschland. Zeitschrift für Feldherpetologie 19: 145–164.

Selcer KW (1986) Life-history of a successful colonizer: The Mediterranean Gekko, *Hemidactylus turcius*, in Southern Texas. Copeia 1986(4): 956–962. doi: 10.2307/1445292

Serrantes P, Galán P (2007) Demotgrafia, estado de conservacion y amenazas de la poblacion de eslizon iberico (*Chalcides bedriagai*) de la playa de Larinio (A Coruña). Boletín de la Asociación Herpetológica Española 18: 15–20.

Seva E, Escarré A (1976) El eslizón ibérico (*Chalcides bedriagai*) en el medio insular de Nueva Tabarca (Provincia de Alicante). Mediterránea: serie de estudios sobre biología terrestre mediterránea 1: 61–115.

Simms C (1972) Shift in a population of northern vipers. British Journal of Herpetology 35: 268–271.

Smirina EM, Ananjeva NB (2007) Growth layers in bones and acrodont teeth of the agamid lizard *Laudakia stoliczkana* (Blanford, 1875) (Agamidae, Sauria). Amphibia-Reptilia 28: 193–204. doi: 10.1163/156853807780202512

Stabler LB, Johnson WL, Locey KJ (2012) A comparison of the Mediterranean gecko (*Hemidactylus turcius*) populations in two temperate urban habitats. Urban Ecosystems 15: 653–666. doi: 10.1007/s11252-011-0216-1

Strijbosch H (1995) Population structure and displacements in *Lacerta vivipara*. In: Llorente GA, Montori A, Santos X, Carretero MA (Eds) Scientia Herpetologica. SEH, Barcelona, 232–236.

Stumpel AHP (2004) Reptiles and Amphibians as Targets for Nature Management. Alterra, Wageningen.

Tomasevic Kolarov N, Ljubisavljevic K, Polovic L, Dzukic G, Kalezic ML (2010) The body size, age structure and growth pattern of the endemic Balkan Mosor rock lizard (*Dinarolacerta mosorensis* Kolombatovic, 1886). Acta Zoologica Academiae Scientiarum Hungaricae 56: 55–71.

Tuniyev SA, Tuniyev BA (2008) Intraspecific variation of the sand lizard (*Lacerta agilis*) from the Western Caucasus and description of a new subspecies *Lacerta agilis mzymtensis* spp. nov. (Reptilia: Sauria). Russian Journal of Herpetology 15: 55–66.

Tvrtkovic N, Lazar B, Tome S (1998) The western green lizard *Lacerta (viridis) bilineata* Daudin, 1804 (Sauria-Lacertidae) in Slovenia and Croatia. Natura Croatia 7: 363–369.

Újavári B, Korsós Z (1997) Thermoregulation and movements of radio-tracked *Vipera ursinii rakosiensis* in Hungary. In: Böhme W, Bischoff W, Ziegler T (Eds) Herpetologia Bonnensis. SEH, Bonn, 367–372.

Vacher J-P, Presseq B, Bertrand A (2003) Découverte du Seps strié *Chalcìdes strìatus* (Cuvier, 1829) (Squamata, Seincidae) dans le département de la Haute-Garonne. Bulletin de la Société. Herpétologique de France 105: 4–8.

Vanhooydonck B, Van Damme R, Aerts P (2000) Ecomorphological correlates of habitat partitioning in Corsican lacertid lizards. Functional Ecology 14: 358–368. doi: 10.1046/j.1365-2435.2000.00430.x

Vignoli L, Vuerich V, Bologna MA (2012) Experimental study of dispersal behaviour in a wall lizard species (*Podarcis sicula*) (Sauria Lacertidae). Ethology Ecology and Evolution 24: 244–256. doi: 10.1080/03949370.2011.643922

Vogrin N (1999) Preliminary note on the morphometric differences between two populations of *Podarcis muralis* (Laurenti, 1786) and *Podarcis muralis maculiventris* (Werner 1891) in Slovenia. Natura Croatia 8: 325–329.

Völkl W, Alfermann D (2007) Die Blindschleiche: die vergessene Echse. Beiheft der Zeitschrift für Feldherpetologie 11: 1–160.

Völkl W, Käsewieter D (2003) Die Schlingnatter: ein heimlicher Jäger. Beiheft der Zeitschrift für Feldherpetologie 6: 1–152.

Völkl W, Thiesmeier B (2002) Die Kreuzotter: ein Leben in festen Bahnen? Beiheft der Zeitschrift für Feldherpetologie 5: 1–159.

Werner Y, Yehudah L (1988) Egg size and egg shape in Near-eastern Gekkonid lizards. Israel Journal of Zoology 35: 192–213.

Zagar A, Osojnik N, Carretero MA (2012) Quantifying the intersexual and interspecific morphometric variation in two resembling sympatric lacertids: *Iberolacerta horvathi* and *Podarcis muralis*. Acta Herpetologica 7: 29–39.

Supplementary material 1

Species names used in our database and used in the Societas Europaea Herpetologica (SEH) atlas

Authors: Annegret Grimm, Ana María Prieto Ramírez, Sylvain Moulherat, Julie Reynaud, Klaus Henle

Data type: Table.

Explanation note: The table matches the species names in the SEH atlas with the updated speceis names used in our database. It thus provides the two species list that can be used to search the database.

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Supplementary material 2

Comments on taxonomy and species coverage

Authors: Annegret Grimm, Ana María Prieto Ramírez, Sylvain Moulherat, Julie Reynaud, Klaus Henle

Data type: Tables.

Explanation note: The supplementary material consists of several tables that explain differences between our updated list of species names to the lists used by Sillero et al. (2014) in their new SEH list of species and the list of Speybroeck et al. (2010).

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