A reassessment on the state of knowledge of Chilean Falconidae in the last hundred years

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Abstract

Eight species of falcons (Falconidae) have been recorded in Chile. To date, all relevant studies considered birds of prey in general, with no specific focus on this family. Based on a comprehensive review of the literature, an updated report is presented on the state of knowledge of falcons in Chile. This data set comprises a total of 165 studies published from 1915 to 2015. Scientific productivity was lowest in 1945-1955 and highest in 2005-2015, with a steady increase since 1985. However, the focus of research in Chile is biased towards two species: Milvago chimango and Falco sparverius. Two administrative regions, Santiago Metropolitan Region and Araucanía, were the most studied whereas Arica, Tarapacá, and Antofagasta regions accounted for fewer than 1% of the studies. Faunistic studies (including abundance) were the most common research topic. It is suggested that the lack of knowledge regarding species in the genus Phalcoboenus may negatively affect the conservation status of these species, and believed that the lack of preference for certain research topics, such as systematics and natural history, are the result of historical factors including the decrease of field biology and perhaps a biased interest of the researchers. Finally, this review highlights the paucity of information on falcons and provides a framework for directing future research.

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Keywords
Birds of prey, Falconidae, Knowledge, Diversity, Chile, Natural history

Introduction

Falcons (family Falconidae) are small to medium sized, exclusively diurnal birds of prey, which are top predators inhabiting a broad range of habitats (Yáñez et al. 1982, Biondi et al. 2005). Falcons are considered good indicators of ecological and environmental health (Rau and Jaksic 2004), as are other birds of prey (Pfeiffer and Meyburg 2015). They fulfill an important role maintaining control over plague species and regulating the ecosystem (Rau 2014). The 64 species are grouped in 11 genera and 2 subfamilies: Polyborinae (caracaras and forest falcons) and Falconinae (true falcons and falconets) (White et al. 1994). Eight species of falcons inhabit Chile: five species of caracaras (Caracara plancus (Miller 1777), Milvago chimango (Vieillot 1816), Phalcoboenus albogularis (Gould 1837), P. australis (Gmelin 1788), and P. megalopterus (Meyen 1834)), and three Falconinae (Falco femoralis (Temmnick 1822), F. peregrinus (Tunstall 1771), and F. sparverius (Linnaeus 1758)).

Research and reviews in Chile have mostly focused on birds of prey in general. A review was carried out by Muñoz-Pedreros and Norambuena (2011), who covered a period of 200 years, and focused on publication type, temporal trends, and research topics. Although only covering 30 years of scientific research, Raimilla et al. (2012) identified a marked bias towards nocturnal species, centering on diet and reproductive aspects. Two other reviews focused on one type of bird of prey. Figueroa et al. (2015) focused on the biology of owls in Chile and relevant conservation strategies. Figueroa (2015) documented a lack of research on the natural history of Milvago chimango. All these investigations are significant as they expose a deficiency in information, and thus, indicate where more research is warranted, regardless of possible limitations typical to this type of studies as indicated by Bimrose et al. (2005). Limitations may include a limited temporal scope, insufficient access to information, and the selection and classification of studies.

Our aim is to describe the current state of knowledge regarding falcons in Chile based on a comprehensive review of the literature. We identify deficiencies in temporal, thematic, geographic, and species-specific knowledge, discuss the possible causes and suggest directions for future research.

Methods

The bibliographical review consisted of an exhaustive search of the ornithological literature on falcons in Chile, published between 1915 and 2015, and presented in scientific publications, national and international journals (both indexed and non-indexed), books, book chapters, and undergraduate and graduate theses (only those with online
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Relative productivity was measured and compared across time (10 year intervals beginning in 1915), space (administrative regions), subject (research topic), and species.

We classified research topics into 13 categories identified by Muñoz-Pedreros and Norambuena (2011). However, due to the lack of literature for some topics, only 11 applied to our data set: Natural History (NH): studies that cover descriptions of morphology, distribution, identification, ecology, and systematics. Field manuals and monographs also fall into this category; Systematics and Taxonomy (ST): studies on classification, description of new species, species reviews, and phylogenetic analyses; Distribution and Biogeography (DB): studies focusing on distribution patterns, updates in distribution ranges, and the study of processes which originate and modify said distribution; Faunistics, Biodiversity, and Abundance (FBA): studies with observation data, new registries, sightings, species diversity, and abundance data. Studies that present abundance data are considered in this category, as ecologic studies contemplate gathering said data along with visual observations and registries, which coincide with the most common methodologies (see: Bibby et al. 1993); Diet and Trophic Ecology (DTE): these studies exclusively observe the feeding preferences of the species, stomach content, pellets, trophic position, trophic chains, and feeding activity; Reproduction and Development (RD): studies related to reproductive characteristics, courting, fertilization, nesting, hatching, number of hatchlings, waiting period in the nest, embryo development, and yearly development period; Ethology, Migration, and Home range (EMH): studies on migratory behavior, patterns, and habits, and home range according to the definition by Burt (1943) as the area occupied by an individual during feeding, mating, and nestling care; Parasitology and Medicine (PM): studies related to the internal or external parasitic flora of the species, new parasite species registries, clinical data, medical reports, and veterinary procedures; Conservation and Legislation (CL): studies regarding conservation plans, conservation state, anthropogenic effects, environmental legislation, hunting manuals, and hunting and closed-season reports; Study Methods and Techniques (SMT): studies on sample recollection and manipulation, notes on observation and data registry, and comparisons between study methods; and “Environmental Education and Science Outreach” (ESO): studies that focus on teaching environmental sciences by using birds of prey to a non-specialists audience.

Publications which did not explicitly mention the scientific or common name(s) of the study species were omitted from our data set.

Results

A total of 165 studies between 1915 and 2015 included scientific data on falcons in Chile. The most studied research topics were “Faunistics, Biodiversity, and Abundance” and “Diet and Trophic Ecology” with 63 and 34 studies, respectively. “Study Methods and Techniques” and “Environmental Education and Science Outreach” were the least studied topics, with 5 and 1 publications, respectively (Figure 1). The
highest productivity was observed during the last 10 years (2005–2015) with 52 publications, in contrast with the decade between 1945 and 1955 which only presented one study (Figure 2). Of the administrative regions (Figure 3), Metropolitan Santiago was best represented with 15% of contributions, followed by Araucanía with 14% and Los Lagos and Magallanes with 13% each. The O’Higgins region contributed no studies. Most (78%) studies were scientific papers, followed by books (11%), and books chapters (10%). Only 1% of publications were theses. Across species, *M. chimango*, *F. sparverius*, and *F. pererinus* were most often mentioned, with 23, 23, and 20% of contributions, respectively. The remaining species contributed fewer than 11% of citations (Figure 4).

In the following section, results are summarized for each one of the research topics:

*Natural history.* The natural history of falcons in Chile is poorly documented. Studies by Quijada (1917), Housse (1934; 1937), and Barros (1960) regarding *M. chimango*, by Housse (1935) regarding *F. sparverius*, and Housse (1936a) regarding *C. plancus* discuss aspects of morphology, behaviour, reproduction, development, foraging, and as well as anecdotal observations of daily activity. Particularly, the complete reproductive cycle of *P. megalopterus* was described by Housse (1937), whereas data
are missing for the remaining species. Figueroa (2015) analyzed the scarce literature regarding the natural history of *M. chimango*.

**Systematics and taxonomy.** The systematics and taxonomy of falcons have been clarified by Fuchs et al. (2012, 2015). They reported polyphyly of the genus *Milvago*, and found that *M. chimango* is part of the *Phalcoboenus* clade and should be transferred to this genus (Fuchs et al. 2012). The genus *Falco* was found to be monophyletic (Fuchs et al. 2015). There is little information regarding intraspecific variation and evolution of falcons in Chile. *Falco sparverius fernandensis* was described by Chapman (1915). Two subspecies of *M. chimanago* are known: *M. chimango temucoensis* (Sclater 1918) is found is most of Chile (Housse 1934) and *M. chimango fuegiensis* (Johnson
Figure 3. Relative abundance of studies published for each administrative region of Chile.

and Behn 1957), which is endemic in Tierra del Fuego. The latter subspecies is no longer recognized as a valid taxon by most taxonomists (e.g. Dickinson & Remsen 2013). Drouilly’s (1968) identification key provides accurate diagnostic recognition characteristics for species classification. McNutt (1984) established that the pale coloration in *F. peregrinus* is recessive in the genotype of the species.
Figure 4. Relative bibliographic importance according to circulation medium and researched species.

**Distribution and biogeography.** The genera *Falco* (Kleinschmidt 1929; Reynolds 1934; Bullock 1949; Torres 1970; Araya et al. 1974; Schlatter 1976; Araya and Millie 1998), *Caracara* (Reynolds 1934), and *Milvago* (Jaksic et al. 2002) can be found from Arica to Magallanes regions. Among *Phalcoboenus*, *P. megalopterus* is the most widely distributed species occurring from the extreme north (Hellmayr 1932) south to Magallanes (Jaksic et al. 2002); *P. albogularis* (Vuilleumier 1985, Cursach et al. 2009) has been sighted once in the central area of Chile, and *P. australis* is limited to the extreme south (Reynolds 1934, Drouilly 1968, Collar 1986, Marín et al. 2006).

**Faunistics, biodiversity, and abundance.** During an extended period, only the presence or absence of species was documented without attention for abundance (e. g. Jaffuel Pirion 1927, Gigoux 1928, Bullock 1929a, Bullock 1929b, Reynolds 1934, Housse 1936b, Philippi 1937, Barros 1937, Bullock 1938, Millie 1938, Larraín 1939,
Population estimates began with general ornithofaunal observations at some locations, albeit in a non-systematic manner, which resulted in low estimates (with the exception of *M. chimango*) (e.g. Cody 1970, Markham 1970, Araya et al. 1974, Schlatter 1976, Ellis and Glinski 1980, Venegas 1981, Figueroa et al. 2000a, Simeone et al. 2008, Imberti 2005). The greatest abundance and number of species were registered in national parks and reserves (e.g. *F. femoralis*, *F. peregrinus*, and *M. chimango* in the National Ñuble Reserve, Estades 1997; *C. plancus*, *F. femoralis*, and *M. chimango* in the Huemules de Niblinto Nature Sanctuary, Figueroa et al. 2000b; and *C. plancus*, *F. peregrinus*, *F. sparverius*, *M. chimango*, and *P. albogularis* in the National Futaleufú Reserve Elgueta et al. 2006).

**Diet and Trophic Ecology.** The feeding preferences and habits of *C. plancus*, *F. femoralis*, *F. sparverius* and *M. chimango* have been described (Barros 1925). *Falco femoralis* exclusively feeds on birds and insects (Jiménez 1993, Jaksic et al. 1993, 1996), depending on the food supply (Figueroa and Corales 2005). *Falco peregrinus* is considered an opportunist (McNutt 1981) and is a top predator of granivore birds (Marquet et al. 1998), as well as an avid insect eater, again depending on supply (Simeone et al. 1997). The feeding habits of *F. sparverius* are known in detail; it is classified as a predator of insects, reptiles (Goodall et al. 1951, Jaksic et al. 1982, Jaksic and Ostfeld 1983, Marquet et al. 1998, Jaksic and Feinsinger 1991, Simeone et al. 1997), and small mammals (Jaksic 1986), and the supply of the latter increases species abundance (Jaksic et al. 1992, Jaksic et al. 1993, 1996). *F. sparverius* is capable of changing its diet following the seasons (Figueroa and Corales 2002, Mella 2002, 2005) and geographic location (Ellis et al. 2002). No trophic superposition between *F. femoralis* and *F. sparverius* has been documented in Chile (Torres-Mura 2004, Rau and Jaksic 2004). The feeding habits and preferences of *M. chimango* are described in detail through stomach content and pellets (Yáñez et al. 1980): it is an omnivore and a scavenger (Núñez and Yáñez 1981, Núñez et al. 1982, Yáñez et al. 1982, Cabezas Schlatter 1987, Jaksic and Simonetti 1987, Sazima and Olmos 2009). Observations by Figueroa et al. (2004) reveal *P. megalopterus* as an insectivore and carnivore of small birds and mammals. Finally, *P. australis* has been described as the most important predator of *Eudyptes chrysocome* (Forster 1781) eggs (Sphenisciformes) (Cursach et al. 2014).

**Reproduction and Development.** Information on reproductive cycle and development is available for *F. sparverius*, *C. plancus*, *M. chimango*, and *P. australis*. Nesting data on *P. megalopterus* in Chile are limited to a monograph by Housse (1937), who presumed the species would nest in the rich vegetation areas of the mountains. In general, falcons begin nesting in early spring, laying between 2 and 4 eggs, with an incubation period of 15 to 20 days (Housse 1934, Housse 1935, Housse 1936a, Morrison and Phillips 2000, Díaz and Armesto 2003, Marín et al. 2006). Raimilla et al. (2014) described cooperation in care and nursing in *P. australis*.

**Ethology, migration, and home environment.** Information for this topic is fragmented across a number of brief publications and reviews. *M. chimango* is a resident species associated with highly urbanized areas (Lobos et al. 2011). *F. sparverius* and *F. peregrinus* are classified as semi-residents (Teneb et al. 2013, Cursach and Rau 2008). The
only migrant species of falcon recorded in Chile is *F. femoralis* (Jaksic and Simonetti 1987). For instance, the species is considered only a summer visitor to Las Chinchillas National Reserve, North of Santiago (Jaksic and Lazo 1999).

**Parasitology and medicine.** Intestinal endoparasite fauna has been described for *M. chimango* (San Martín et al. 2006), and included bacteria (*Haemoproteus tinnunculi* (Wasielewski and Wilker 1918), *Leucocytozoon toddi* (Sambon 1908) (Protozoa: Haemosporine) (Forrester et al. 2001)), and ectoparasites (new Ischnocera species (Insecta: Phthiraptera) (Mey and González-Acuña 2000), and *Argas (persicargas) keiransi* (Acari: Argasidae) sampled from the neck (Estrada-Peña et al. 2003)). *Escherichia coli* (San Martín et al. 2006) has been identified as a cause of fatal meningoencephalitis in *Milvago chimango* (Seguel et al. 2012). The parasites described and registered in other species of falcons include *Degeeriella rufa* (Phthiraptera: Philopteridae) in *F. femoralis* and *F. peregrinus*; *Acutifrons megalopterus* (Carriker, 1956) (Phthiraptera: Ischnocera) and *Colpocephalum megalopteri* (Price 1967) (Phthiraptera: Menoponidae) in *P. mega- lopterus*; and *Laemobothrion tinnunculi* (Phthiraptera: Laemobothriidae) (González-Acuña et al. 2008) and nematodes, cestodes, and trematodes (Gonzáles-Acuña et al. 2011) in *F. sparverius*.

**Conservation and legislation.** The only species of falcons in Chile which are considered to warrant conservation priority are *P. albogularis* and *P. australis* (Pavéz 2004, Trejo 2007). However, the mechanisms and processes that affect their population have not been identified. Population size of *F. sparverius* and *M. chimango* in San Carlos de Apoquindo in the Andean foothills of Santiago has decreased over time (Pavéz et al. 2010). These species, along with *F. peregrinus*, are at risk for population decrease due to anthropogenic factors (Díaz and Armesto 2003), including accidents such as electrocution on high-voltage lines (González et al. 2014). Tala and Iriarte (2004) provide important data regarding legislation and potential threats to falcons.

**Study methods and techniques.** Studies focusing on study methods and techniques are few. Nevertheless, much information is available on capture and monitoring (Pavéz 2004), diet (Yáñez et al. 1980; Muñoz-Pedreros and Rau 2004), observation and counting techniques (Márquez et al. 2004), and use of baits (Contreras and González 2007).

**Environmental education and science outreach.** The single paper on this subject (Figueroa 1995) provides a plan for teaching ecology and environmental biology through the use of birds of prey, including *M. chimango* and *F. sparverius* species.

**Discussion**

The results presented here show that knowledge on falcons in Chile is uneven across species, research topics and administrative regions. Despite the limitations of this type of study, our data have the advantage of directly visualizing gaps in knowledge of specific topics (Bimrose et al. 2005). Previous reviews (e.g. Muñoz-Pedreros and Norambuena 2011, Raimilla et al. 2012) have demonstrated a recent increase in productivity, mostly resulting from the work of dedicated researchers (Bierregaard 1995).
Given that the classification of research topics used were those of Muñoz-Pedreros and Norambuena (2011), it is not surprising that our review finds similar trends in productivity and circulation medium. Comparison to the study by Raimilla et al. (2012) is hampered by the fact that their findings were not reported separately by species and administrative region. Nevertheless, two clear patterns emerge from these two reviews and the present study: productivity has increased considerably during the last 30 years for birds of prey in general and for Falconidae in particular, and peer-reviewed publications are the most frequently-used circulation medium to report study results. These patterns are not exclusive to these groups but represent a general trend in all sciences (Bornmann and Mutz 2015).

Our review shows that the most common research topic in studies of falcons is “Faunistics, Diversity, and Abundance” and that M. chimango is the most frequent study species. In contrast, Raimilla et al. (2012) found that, studies focusing on “diet” were the most common study subject and F. sparverius was the most commonly studied species of falcon. Population trends in time are hampered by the fact that older studies typically represented reports of the presence of species and provided no data on abundance. In contrast to Raimilla et al. (2012), we found that studies of M. chimango outnumbered those of F. sparverius. However, in agreement with Raimilla et al. (2012) we found that members of the genus Phalcoboenus are poorly covered in the literature, as underscored by the absence of studies on four of the ten study topics.

The concentration of publications on falcons in a small number of regions (Metropolitan Santiago, Araucanía, Los Lagos, and Magallanes) reflects the location of research centers (Raimilla et al. 2012). The same pattern was observed in works that focus on community structure (Jaksic 1985) and continental water birds (Victoriano et al. 2006). There were no studies which report on falcons in the O’Higgins region (central Chile) despite its proximity to the Metropolitan region. The lack of studies may be due to changes in regional administration throughout time (Errázuriz 1998) that may lead to incorrect registry of avifauna near the political-geographic limits. Future studies should focus on poorly studied areas, especially those within a biodiversity hotspot such as Los Ríos and Aysén regions (Arroyo et al. 2008). Our review indicates that some topics remain little studied. Publications on “Study Techniques and Methods” were rare (five citations). We suggest these topics warrant further study because current studies are carried out based on protocols developed for falcons in the northern hemisphere (e.g. Bird and Bildstein 2007) which may not be optimal for research in Chile. The lack of knowledge on the biology of species native to Chile may hamper the application of techniques developed elsewhere for other species. The use of non-suitable techniques may produce biases or errors and perhaps even harm captured individuals (Ford 2003).

Only a single study dealt with “environmental education and divulgation” of falcons (Figueroa 1995). Other works have presented a complete bird of prey education program, but mainly focused on birds of prey in general (e.g. Möler and Muñoz and Pedreros 2004). Nevertheless, both studies illustrate how birds of prey (including falcons) may be used to increase awareness of various environmental problems to a non-specialized audience.
Knowledge on “natural History” is deficient for most species of falcons in Chile. Figueroa (2015) suggested that the lack of knowledge on natural history of *M. chimango* results from historical factors, a shift from field biology to other types of study, difficulties in studying diet, and perhaps changing interests of researchers. These factors may also apply to the study of other species of falcons in Chile.

**Conclusions**

This review of the state of knowledge on falcons in Chile indicates bias in all assessed categories: research topics are biased towards faunistic data; geographically, with many subsampled or unsampled regions; and in preferred species, with two major researched species. Due to the increase in scientific productivity for Falconidae and birds of prey, especially in recent years, reporting where information is lacking and which regions and species have not been studied is essential to continue the study of this group optimally. Much remains to be done and further research is needed. We hope this work may provide an impetus to fill the historical, ecological, and geographical gaps in knowledge.

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