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THE EFFECT OF INTRODUCED SPECIES ON RAPTORS

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ABSTRACT.—Biological invasions are considered one of the major threats to the Earth's biota, and their prevention and control are widely recommended. A critical step is to gather information on the effects of introduced species on native species. In such analysis, it is important to consider both the negative effects and the fact that many nonnatives have become key components of existing ecosystems. The effects of nonnatives are particularly worrisome for raptors because raptors have high trophic positions and their ecological role can structure native communities. We here examine the effects of introduced species on raptors, as well as the interest in studying these effects, through a review of the published literature. The numbers of studies on raptors and introduced species as individual topics are rapidly increasing, but despite this we found few articles relating the two topics and fewer still with a clear aim of studying this relationship. Although the number of published reports we found was low, articles indicating negative effects outnumbered articles showing positive ones. Negative effects identified included decrease in native prey and direct or indirect poisoning via poisons aiming to protect productive introduced species from predators or to control introduced pests. Positive effects identified included extension of distributional range facilitated by introduced species or nonnative species as a food source. Very importantly, native raptors can become dependent on introduced species, and any proposed control of the nonnative/introduced species merits careful evaluation. In conclusion, the effects of nonnative species on this key group of top predators and scavengers have been poorly considered, but merit special attention and specific design in future studies.

KEY WORDS: *diet; exotic species; invasive species; nesting habitat; prey; raptor.*

EL EFECTO DE LAS ESPECIES INTRODUCIDAS EN LAS RAPACES

RESUMEN.—Las invasiones biológicas son una de las peores amenazas para la biodiversidad, y el control y la prevención de nuevas introducciones son ampliamente recomendados. Un paso fundamental en este proceso es la generación de conocimiento acerca del efecto de las especies introducidas sobre las especies nativas. En tal análisis, es importante considerar tanto los efectos negativos como el hecho de que algunas especies no nativas han llegado a convertirse en componentes clave de ecosistemas actuales. El efecto de las especies introducidas es especialmente preocupante para las rapaces debido a que, por su posición trófica y su rol ecológico, estas últimas pueden estructurar las comunidades nativas. Analizamos los impactos producidos por las especies introducidas sobre las rapaces y el interés en estudiarlos, mediante la revisión de la bibliografía publicada sobre el tema. Los estudios sobre rapaces y sobre especies introducidas como temas separados están aumentando rápidamente, pero a pesar de esto encontramos pocos artículos relacionando ambos temas y menos aún con un objetivo claro de estudiar dicha relación. Aunque el número de artículos encontrados fue bajo, los artículos que mostraban un efecto negativo han sido más numerosos que aquellos que indicaban un efecto positivo. Los efectos negativos identificados incluyeron la disminución de las presas nativas y el envenenamiento directo o indirecto producido por el veneno utilizado para la protección de especies introducidas económicamente productivas o para controlar especies introducidas consideradas pestes. Los impactos positivos identificados incluyeron la extensión del área de distribución facilitada por especies introducidas o las especies introducidas como fuente de alimento. Es importante notar que incluso las especies nativas pueden llegar a depender de las especies introducidas, y por lo tanto cualquier medida de control merece una cuidadosa evaluación. Concluyendo, las implicancias de las especies introducidas sobre este grupo clave de depredadores y carroñeros han sido poco consideradas pero merecen una atención especial y un diseño adecuado en estudios futuros.

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The introduction of nonnative species can have severe consequences for native species and ecosystems (Carlsson et al. 2009, Vilà et al. 2011). As a result, the Convention on Biodiversity exhorted the contracting parties ''to prevent the introduction, control or eradicate those alien species which threaten ecosystems, habitat or species.'' Managers of eradication programs must consider, however, that invasive species have far-reaching effects throughout the entire ecosystem, which may cause a control program to result in unintended negative outcomes for native species (Tablado et al. 2010). To address the Convention's aims appropriately and effectively, knowledge of the full effects of introduced species over a wide range of ecosystems and species is required.

The study of biological invasions is rather a new discipline and is growing rapidly on some continents (Pyšek et al. 2008, Speziale et al. 2012). Studies show that nonnative species introductions may produce varying effects on native biotas (Gurevitch and Padilla 2004, Rodriguez 2006, Vilà et al. 2011). However, the analysis of the relationships between introduced species and certain taxa, including raptors, are poorly studied. A review of existing literature to find knowledge gaps may be helpful in guiding future research of the effects of this threat to biodiversity, particularly for raptors.

Raptors can directly promote high biodiversity through resource facilitation (i.e., food resources that are made available by raptors) and through trophic cascades by exerting top-down forces (Estes et al. 2001, Soulé et al. 2005, Sergio et al. 2007, 2008). They may also act as biodiversity indicators by being spatiotemporally associated with biodiversity (Sergio et al. 2008). As top predators and rare species, raptors can be threatened by species population changes at lower trophic levels (Begon et al. 2006, Wilson and Wolkovich 2011). Thus, it is important to monitor the effects of alien species on these top predators. The net effect of introduced species will depend on their capacity to modify the ecosystems and produce cascading effects (Crooks 2002). The goals of our study were (a) to analyze whether the volume of research on the relationship between raptors and exotic species follows the trend of the study of introduced species in general, and (b) to evaluate the effects of nonnative species on raptors by reviewing existing published studies.

MATERIALS AND METHODS

We used the ISI Web of Knowledge engine to search for articles on biological invasions as related to raptor species. We first performed two separate searches to compare the trend of biological invasions science and raptor science over time. For that we searched title, abstract, and key words for the terms (inva* OR introduced OR alien OR exotic OR nonnative OR nonindigenous) in one search and for (condor OR raptor OR vulture) separately. Then we searched for published articles relating raptors and introduced species by using the following criteria: ''(raptor OR vulture OR condor) AND (inva* OR introduced OR alien OR exotic OR nonnative OR nonindigenous).'' We refined each search to identify only articles published in journals related to biological or environmental sciences. We performed the search in May 2012 and included articles published up to and including December 2011. We calculated the rate of publication of articles relating raptors and introduced species in respect to total publications in raptor science as a measure of the interest in the effect of nonnative species (hereafter the ''exotics in raptor science index''). We conducted an analysis of covariance (ANCOVA) to compare the former rate of publication to the general interest in introduced species over the last 20 yr with the year as a covariate. For that we also calculated the ratio between publications in nonnative species (see criteria above) and the total publication in biological or environmental sciences as a measure of the interest in the study of introduced species in general (by searching the ISI Web of Science the word ''species'' and refining the search to identify only articles published in journals related to biological or environmental sciences (hereafter the ''exotics in general science index'').

We then analyzed each article looking for information on the effects of the introduced species on raptor species to disentangle whether the overall described impact was positive, negative, or neutral. We defined a positive impact when the introduced species possibly favors raptors based on the information provided by the study (e.g., expanded distribution, increased nesting locations, increased food supply, or greater reproductive success). We considered an effect as negative when an introduced species directly or indirectly damages raptors in any way (e.g., via reduced prey availability, direct or indirect poisoning, etc.). We classified effects of introduced species as neutral when we could not classify them as either positive or negative for raptor species, according to the data provided by the study or if this information was ambiguous. We also analyzed trophic relationships affecting raptors, distinguishing

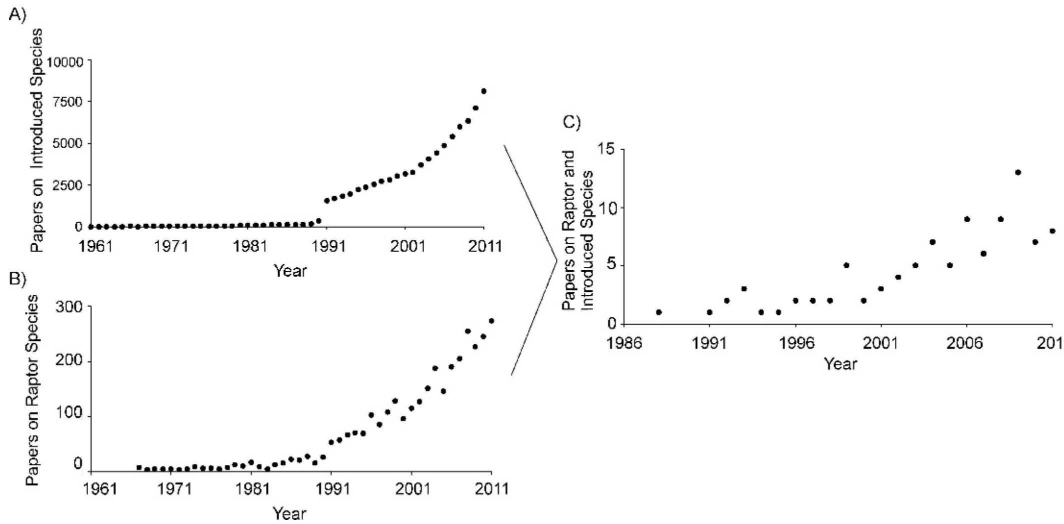

Figure 1. Trends of papers yielded by ISI Web of Science searches (see Methods for details) published on: (A) introduced species studies; (B) raptors studies; and (C) raptors in relation to introduced species. Notice the differences in y-axis scale among graphs.

between introduced primary producers (as habitat-modifiers), consumers (as prey for raptors and scavengers), top predators, and pathogens.

RESULTS

The volume of both biological invasion research (Fig. 1A) and raptor research has increased greatly in the last 20 yr (Fig. 1B). However, although research analyzing the relationship between introduced species and raptors has increased, this increase was more moderate (Fig. 1C). Part of this trend may be related to the growth of raptor science *per se*, but it apparently does not reflect the great interest in biological invasions. We found that the interest in studying the effect of introduced species is much higher in general sciences than in raptor science: ANCOVA comparing publications on the effects of introduced species in raptor science (studies on introduced species and raptors over studies on only raptors) with that of general sciences (studies on introduced species within biological or environmental sciences over biological or environmental sciences studies in general) between 1991 and 2011 with the year as a covariate ($F_{1,39} = 1468.4$; $P < 0.001$; Fig. 2).

Our systematic search yielded a total of 97 articles that include in the same article one or more raptor species and one or more introduced species. After reviewing each one, we found that only 32% (31 articles) actually analyzed the relationship between raptors and nonnative species. We did not include those articles analyzing the effects of native species extending their distributions and thus considered newly arrived in a raptor ecosystem (e.g., Gutiérrez et al. 2006, Carrete et al. 2010), because in many cases it is not clear if it is a natural or human-mediated expansion. We included a total of 31 articles in our analyses. Of these 31 articles, only about 32% (10) had a clear *a priori* aim of studying nonnative species. We found studies of raptors and nonnative species on every continent (except for Antarctica; Fig. 3). Although the number of articles found for each continent was low, the effect of the introduced species on raptors appears to be widely distributed (Fig. 3). The analysis of the 31 articles showed that the outcome of nonnative species introductions could either be positive, negative, or neutral. In total, articles on the negative effects outnumbered articles on positive ones (16 to 11, respectively). Considering trophic relationships, based on the articles analyzed, producers modified raptors' habitats, generating indirect effects (Fig. 4). Introduced consumers (prey for raptors) and pathogens directly affect raptors, whereas introduced predators do so indirectly by competing for the same prey (Fig. 4). We found predators and pathogens only exerted negative effects (or neutral in one case), whereas the effect of producers and prey were both negative and positive (Fig. 4; Table 1).

Introduced primary producers causing habitat-modification effects on raptors were the focus of 39%

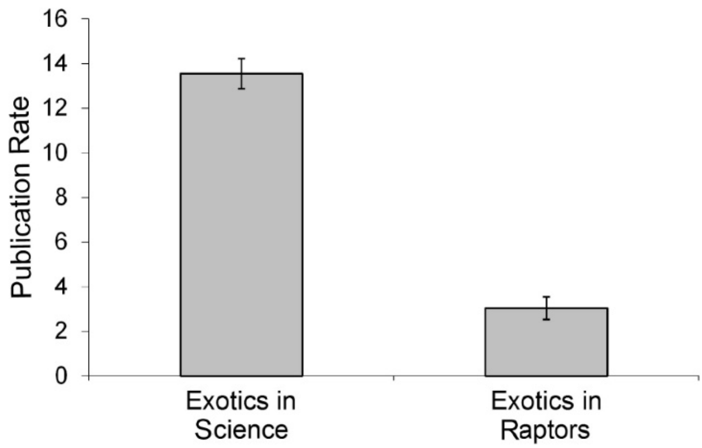

Figure 2. Differences in the interest in publishing the effects of introduced species in raptors science (Exotics in raptors science index) with that of general sciences (Exotics in general science index). Vertical bars denote standard errors. See Methods for more details.

(12/31) of the selected 31 articles, either by providing nest sites or by allowing the species to extend their distributions. Of these articles, 33% (4 of 12) indicated that raptors species were able to extend their distributions due to the new habitat conditions (e.g., finding new places to nest or perch, to rest or hunt; Table 1). Half of the studies (6 of 12) showed negative impacts of plantations or even-aged monotypic stands of introduced species (Table 1). These studies showed increased nest failures, reduced productivity, or even nest abandonment, arguing that it could be due to reduced prey availability in the new habitats. Two of these articles also reported a neutral impact. We also found two studies showing both positive (expanded distribution and use of human-modified land) and negative (changed roosting behavior and exotic plantations devoid of birds) effects at the same time (Table 1).

Introduced prey as part of raptors' diet was studied in 48% out of the 31 articles analyzed. Articles showing that raptor species feed on nonnative species, which may be considered as a positive outcome for raptors, made up almost half of diet studies (7 of 15; Table 1). The same proportion of studies (7 of 15) showed negative effects. Several of these latter ones (4 of 7) analyzed the effects of poison used to control introduced species, indirectly affecting raptors that fed on this prey. Another two studies evaluated lead poisoning in raptors caused by the consumption of introduced species contaminated or hunted with lead ammunition. Another article

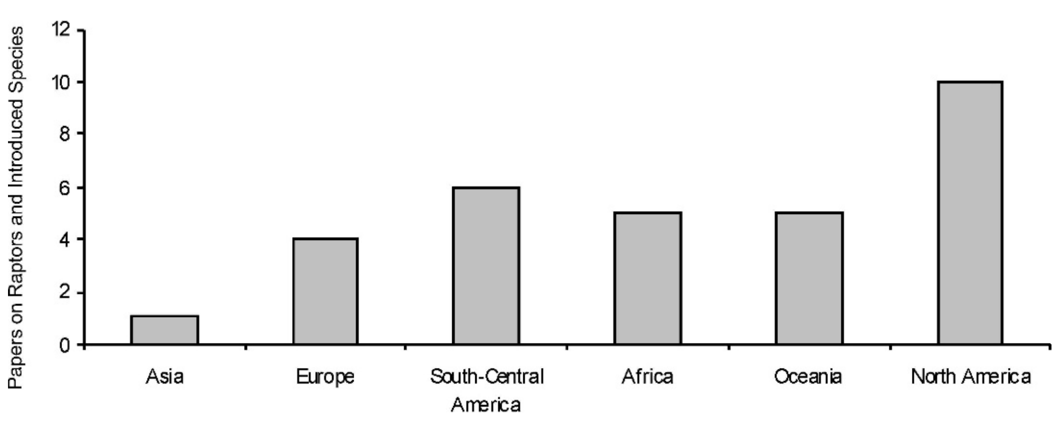

Figure 3. Geographical distribution of the number of papers relating raptors with introduced species in each continent based on a search of articles in the ISI Web of Science (see Methods for details).

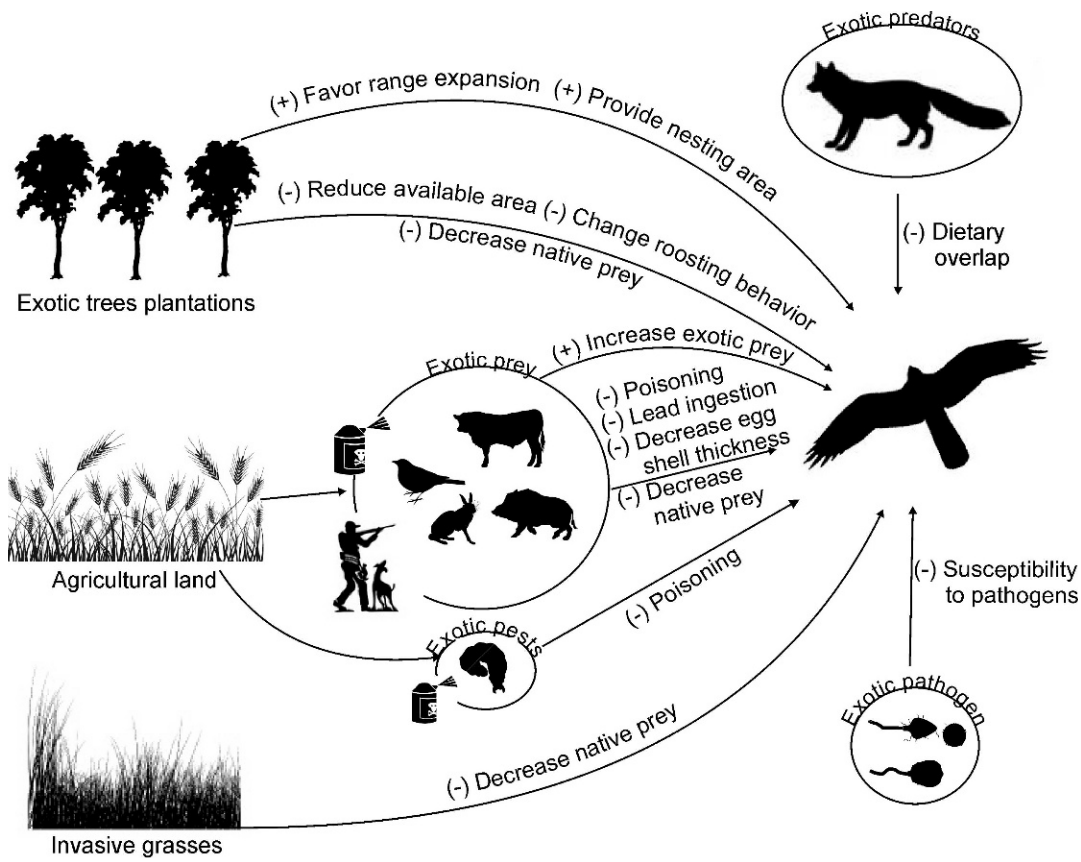

Figure 4. Different positive (+) and negative (−) biotic interactions among introduced species and raptors found in a bibliographic search. See Table 1 for further details.

indicated the mortal effect of an antiinflammatory drug (diclofenac) used for cattle treatment (Table 1). Neutral effects were considered by three studies (two of which also showed a positive and a negative impact each and were considered above), indicating either that introduced species were minor parts of the raptors' diet or that a change in migration patterns was produced (Table 1).

The remaining articles (13% or 4 articles) of the 31 studies dealt with topics unrelated to introduced prey or to habitat modification. All but one showed negative effects on raptors (Table 1). These included competition with nonnative species (mammalian), and susceptibility to exotic pathogens. Only one of these articles reported a neutral effect.

DISCUSSION

The study of nonnative species has become increasingly popular in recent years (Pyšek et al. 2008, Speziale et al. 2012). Similarly, there has been increased interest in the study of raptors. However, such an increase has not been seen in the study of raptors relative to introduced species and their effects. Any literature search can suffer from biases related to the databases or keywords used. It is likely, however, that any source of bias would only minimally affect the general patterns in publication efforts, and thus our general conclusions on the effects of nonnative species on raptors. Our results suggest that ecologists studying this group of species may not yet be highly concerned with the effect of one of the most important threats to wildlife: the introduction of nonnative species (Sala et al. 2000, Pereira et al. 2010). One fact that may be influencing this result is that raptors themselves do not commonly become invasive species.

We found that raptors are affected by nonnative species within their natural distribution areas, both

Table 1. Results of the search of peer-reviewed studies in the ISI Web of Knowledge summarizing the aims of the study and effects of introduced species on raptors. The sign or letter within brackets indicates whether the effect is considered as positive (+), negative (−) or neutral (N) (see Methods for definitions).

RAPTOR SPECIES	INTRODUCED SPECIES	EFFECT	STUDY AIM	REF.
Egyptian Vulture (*Neophron percnopterus*) and Eurasian Buzzard (*Buteo buteo insularum*)	Domestic goats (*Capra hircus*)	(+) Introduced species are part of raptors' diets	Describe relationship among introduced and native	1
Ogasawara Buzzard (*Buteo buteo toyoshima*)	Black rat (*Rattus rattus*), house mouse (*Mus musculus*) green anole (*Anolis carolinensis*) marine toad (*Bufo marinus*)	(+) Introduced species are dominant in raptor diet	Study diet and describe basic ecology	2
Andean Condor (*Vultur gryphus*)	Livestock, red deer (*Cervus elaphus*) and hare (*Lepus europaeus*)	(+) Heavy dependence on nonnative herbivores (98.5% of the diet) as a food source	Spatial and temporal variation in the diet	3
Red-tailed Hawk (*Buteo jamaicensis*), Sharp-shinned Hawk (*Accipiter striatus*), Cooper's Hawk (*Accipiter cooperii*)	Chukars (*Alectoris chukar*)	(+) Chukars are an important food resource for migrating raptors	Estimate survival, and identify causes of mortality of chukars	4
Black-chested Buzzard Eagle (*Geranoaetus melanoleucus*) and Harris's Hawk (*Parabuteo unicinctus*)	European rabbit (*Oryctolagus cuniculus*)	(+) Marked decrease of native rodent prey *Octodon degus* and concomitant increase of nonnative rabbit	Study changes of land use and its effects on vegetation, small mammals and raptors	5
Hawaiian Hawk (*Buteo solitarius*)	Several introduced birds and mammal	(+) Introduced species are dominant in raptors' diets	Study reproduction and factors affecting it	6
Black-chested Buzzard Eagle, Magellanic Horned Owl (*Bubo magellanicus*) and Red-backed Hawk (*Buteo polyosoma*)	European hare (*Lepus europaeus*)	(+) Black-chested Buzzard Eagle takes advantage of hares (N) Other raptors eat hares but mainly native prey	Assess the food habits of three raptors in relation to introduced hare	7
Peregrine Falcon (*Falco peregrinus*), Red-tailed Hawk, Barn Owl (*Tyto alba*), Burrowing Owl (*Athene cunicularia*)	Black rats (*Rattus rattus*)	(−) Rodenticide used to erradicate rats produced death of raptors	Report on the eradication of introduced species	8
Bald Eagle (*Haliaeetus leucocephalus*)	Wireworm (*Agriotes* spp.) pests on potato and other root crops	(−) Fonofos is found in ingesta of birds with severely inhibited brain and/or plasma cholinesterase activity	Investigate cause of death of select birds of prey	9
California Condor (*Gymnogyps californianus*)	Wild boar (*Sus scrofa*)	(−) Incidental ingestion of lead ammunition embedded in wild boar carcasses	Test if lead in California Condors comes from ingestion of spent ammunition	10
Swamp Harrier (*Circus approximans*), and Southern Boobook (*Ninox novaeseelandiae*)	Rabbits (*Oryctolagus cuniculcus*), brushtail possums (*Trichosurus vulpecula*), wallabies (*Macropus* spp.)	(−) Raptors found dead from secondary poisoning	Analyze the effects of brodifacoum in nontarget species	11

Table 1. Continued.

Raptor Species	Introduced Species	Effect	Study Aim	Ref.
Swamp Harrier and Southern Boobook	Norway rats (*Rattus norvegicus*) and ship rats (*Rattus rattus*) among others	(−) Raptors found dead from secondary poisoning	Not specified	12
Cape Vulture (*Gyps coprotheres*)	Cattle	(−) Birds died within 48 hr of dosing with diclofenac used as veterinary treatment of cattle	Test raptor sensitivity to diclofenac	13
Sharp-shinned Hawk and Merlin (*Falco columbarius*)	House sparrow (*Passer domesticus*)	(−) Raptor ate House Sparrow containing elevated blood lead concentrations (N) Raptors may be changing migration pattern due to availability of nonnative prey	Evaluate the threat of lead exposure for raptors	14
Black Kite (*Milvus migrans*) and Whistling Kite (*Haliastur sphenurus*)	Cane toads (*Bufo marinus*)	(N) Raptors eat only the tongue of cane toads	Quantified offtake of dead (road-killed) cane toads	15
Black Goshawk (*Accipiter melanoleucus*)	Pine trees (mostly *P. radiata* and *P. pinea*), Domestic pigeons and chickens (*Gallus gallus*)	(+) Multiple brooding due to adaptability to modified environments, and to introduced prey	Report on multiple-brooding	16
Red-tailed Hawk	Mesquite trees (*Prosopis velutina*)	(+) Expanded their range as trees have invaded formerly open desert grasslands	Study habitat selection in mesquite-invaded desert grasslands	17
Northern Harrier (*Circus cyaneus*)	Nonnative conifer plantations	(+) Nonnative conifers were mainly selected for nesting	Study nest-site selection	18
Black Goshawk (*Accipiter melanoleucus*)	Eucalyptus (*Eucalyptus* spp.), pine (*Pinus* spp.), and poplar (*Populus* spp.)	(+) Raptors used introduced trees for nesting	Provide guidelines for favoring nest-tree habitat in plantations	19
Swainson's Hawk (*Buteo swainsoni*)	Eucalyptus (*Eucalyptus viminalis*), Siberian elm (*Ulmus pumila*), pines (*Pinus* spp.) and cypress (*Cupressus* spp.)	(+) Expansion of the suitable habitat (−) Changed communal roosting behavior	Characterize the sites used by hawks for communal roosting	20
Yellow-headed Caracara (*Milvago chimachima*), Crested Caracara (*Caracara plancus*), Savanna Hawk (*Buteogallus meridionalis*), White-tailed Kite (*Elanus leucurus*), Peregrine Falcon, and Northern Harrier	Pines (*Pinus caribea*) and agricultural land	(+) Raptors use cattle pastures and rice fields (−) *Pinus caribea* plantations were almost devoid of birds	Examine community richness, abundance and composition	21

Table 1. Continued.

RAPTOR SPECIES	INTRODUCED SPECIES	EFFECT	STUDY AIM	REF.
Chimango Caracara (*Milvago chimango*)	Gorse (*Ulex europea*), Douglas fir (*Pseudotsuga menziesii*), cypress (*Cupressus* spp.) and pine (*Pinus* spp.)	(+) High productivity associated to nonnative trees and shrubs	Report data on the nesting habitat and nest success	22
Whistling Kite, Brahminy Kite (*Haliastur indus*), White-bellied Sea-Eagle (*Haliaeetus leucogaster*), Western Marsh-Harrier (*Circus aeruginosus*), Collared Sparrowhawk (*Accipiter cirrhocephalus*), Peregrine Falcon, Grey Falcon (*Falco hypoleucos*), Australian Hobby (*Falco longipennis*), and Southern Boobook	Agricultural land treated with pesticides	(−) Eggshell thickness decreased	Investigate temporal and geographical patterns of eggshell thinning	23
Golden Eagle (*Aquila chrysaetos*)	Nonnative conifer plantations	(−) Several territories were abandoned during the earliest phases of forest planting (N) Relatively few were apparently lost to later plantings	Examine the effects of commercial planting on breeding success and occupancy	24
Mauritius Kestrel (*Falco punctatus*)	*Eucalyptus globulus, Ravenala madagascariensis* and agamid lizard (*Calotes versicolor*)	(−) Agricultural encroachment. Even-aged monotypic stands of introduced species are of little value. (N) Juvenile kestrels use semi-invaded forests	Test how forest degradation affects habitat use	25
Prairie Falcon (*Falco mexicanus*), Red-tailed Hawk, Ferruginous Hawk (*Buteo regalis*)	Cheatgrass (*Bromus tectorum*) and other nonnative annuals	(−) Reduced availability of prey	Determine how vegetation changes affect prey	26
Raptors such as Shikra and Gabar Goshawk (*Micronisus gabar*)	*Prosopis* sp. woodland	(−) Raptors were absent from *Prosopis* woodlands	Study species richness and diversity of birds in native and nonnative woodland types	27
Cooper's Hawk, Red-tailed Hawk, and Great Horned Owl (*Bubo virginianus*)	West Nile virus (WNV)	(N) Tested positive for WNV antibodies but no apparent adverse effects of WNV infections	Determine the presence and prevalence of WNV infection	28
Egyptian Vulture	Nonnative pathogens	(−) High susceptibility to infection found in insular vultures	Compare immune response to nonnative pathogens in insular and continental populations	29

Table 1. Continued.

RAPTOR SPECIES	INTRODUCED SPECIES	EFFECT	STUDY AIM	REF.
American Kestrel (*Falco sparverius*)	Nonnative pathogenic avian influenza virus (HPAIV)	(−) Kestrels are highly susceptible to HPAIV producing severe neurologic disease	Examine the effects of nonnative pathogenic HPAIV (H5N1) infection	30
Powerful Owl (*Ninox strenua*)	Lace monitors (*Varanus varius*), foxes (*Vulpes vulpes*), spotted-tailed quolls (*Dasyurus maculatus*)	(−) Medium dietary overlap	Describe the diet and diet overlap	31

References: (1) Gangoso et al. 2006, (2) Kato and Suzuki 2005, (3) Lambertucci et al. (2009), (4) Robinson et al. 2010, (5) Pavez et al. 2010, (6) Griffin et al. 1998, (7) Monserrat et al. 2005, (8) Howald et al. 2009, (9) Elliott et al. 2008, (10) Church et al. 2006, (11) Eason and Spurr 1995, (12) Eason et al. 2002, (13) Naidoo et al. 2009, (14) Chandler et al. 2004, (15) Beckmann and Shine 2011, (16) Curtis et al. 2005, (17) Hobbs et al. 2006, (18) Wilson et al. 2009, (19) Malan and Robinson 2001, (20) Malan and Robinson 2001, (21) Sarasola and Negro 2006, (21) Petit et al. 1999, (22) Morrison and Phillips 2000, (23) Olsen et al. 1993, (24) Whitfield et al. 2007, (25) Burgess et al. 2009, (26) Yensen et al. 1992, (27) Dean et al. 2002, (28) Stout et al. 2005, (29) Gangoso et al. 2009, (30) Hall et al. 2009, (31) Pascoe et al. 2011.

negatively and positively, and that articles showing negative effects outnumbered articles showing positive ones. Regarding the latter, studies show that raptors can strongly rely on introduced species as a food source or for providing nesting habitat (Sarasola and Negro 2006, Gangoso et al. 2006, Lambertucci et al. 2009, Tablado et al. 2010). As introduced prey become abundant, the probability of a native predator using that prey also increases (Rodriguez 2006). Many native predators adapt to feeding on introduced prey, which can become an important part of their diet and some species can obtain a fitness advantage over species that do not adapt to utilizing the prey (Carlsson et al. 2009). This can lead to a high dependence on introduced species and therefore any change in their availability may have direct or indirect impacts on raptors. This can be a particularly critical factor when native resources decrease due to human intervention (Pavez et al. 2010, Akatani et al. 2011, Lambertucci and Speziale 2011). Some threatened raptor populations are in fact maintained by feeding on exotic resources (Chamberlain et al. 2005, Gangoso et al. 2006, Lambertucci et al. 2009).

Introduced primary producers also exert positive effects. Raptors take advantage of the availability of certain introduced trees, particularly when native vegetation is cut down or new plantations modify the habitat (Sarasola and Negro 2006, Akatani et al. 2011). Most studies that report species using novel habitats created by primary producers (*sensu* Hobbs et al. 2006; e.g., introduced species plantations) are not exhaustive and have not studied other fitness indicators such as breeding success or nestling survival, as the effects of introduced species were non-expected results (Wilson et al. 2009). Thus, the question remains as to whether the identified positive outcomes were truly positive.

Negative effects exerted by nonnative species ranged from poisoning and pathogen susceptibility to habitat loss and diminished native prey. Particularly important are the consequences of habitat modification by introduced primary producers, which structure the ecosystems in such a way to directly or indirectly provoke an array of negative effects. For example, the new habitat could be considered a sink for the newly arrived raptor species if the shift toward introduced species is detrimental for certain age classes (Cattau et al. 2010). Nonnative species plantations also provoke other negative effects such as nest failure or territory abandonment, and some may not be used by birds at all (Petit et al. 1999, Whitfield et al. 2007, Seaton et al. 2009).

Similarly, introduced prey species can have positive or negative effects on native raptors. Despite the fact that introduced prey increases the available food source for raptors, they can also provoke important negative effects. Fitness indicators for raptors feeding on the introduced apple snail (*Pomacea insularum*) in the U.S.A. showed that when raptors fed on this introduced prey, juveniles obtained a lower energetic reward than when feeding on native species, thus depressing juvenile survival (Cattau et al. 2010). Other studies have reported that raptors and scavengers can be indirectly affected when feeding in productive systems and that they can be negatively affected by drugs such as diclofenac, used to treat cattle (Naidoo et al. 2009). They can also die through poisoning by feeding on introduced prey, which has either been poisoned to reduce their threat to productive ecosystems, or poisons the raptor through ingestion of lead ammunition used during hunting of the introduced prey species (Eason et al. 2002, Church et al. 2006, Elliott et al. 2008, Lambertucci et al. 2011).

CONCLUSIONS

Several studies report some positive effects of nonnative species on raptors, particularly by providing bottom-up benefits (e.g., food). However, introduced species may also exert negative bottom-up effects (e.g., reduced juvenile survival or nesting failure) and we found that it is the negative effects that are more common and varied throughout the analyzed literature. These two contrasting results merit special attention. Control of or eradication actions for introduced species are often advised, particularly when negative effects of their presence have been recorded. However, the role that nonnative species play in the new ecosystem should be identified before programs are outlined. If raptors (or other native species) depend heavily on the introduced species, then target actions should focus first on how to overcome the problem of eradicating the nonnative species without affecting the species that depend on them (Lambertucci et al. 2009, Akatani et al. 2011). For introduced prey species, alternative native prey must be favored before the introduced one is eradiated. Similarly, considering raptors that rely on primary producers mostly for nesting, it is advisable to provide nesting structures or to recover native vegetation when eradicating introduced trees.

Raptors and scavengers perform a variety of keystone ecological services, such as disposing of carcasses, control of rodent populations and other top-down regulations (Sekercioglu et al. 2004, Sekercioglu 2006, Markandya et al. 2008, Newton 2010, Wilson and Wolkovich 2011), which can be affected by introduced species. Primarily it is important to design specific studies to analyze how nonnative species affect the roles raptors perform on ecosystems. It might be valuable to analyze the fitness and the viability of populations that have taken advantage of this novel (introduced) resource to test whether it really favors raptors. It is also important to analyze the role of introduced species in disturbing the native habitat, prey availability or the interactions within ecosystems. Study of the implications of nonnative species for this key group of top predators and scavengers is currently poorly considered and merits special attention and specific design in future studies.

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