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Conservation risks of exotic chukars (*Alectoris chukar*) and their associated management: implications for a widely introduced phasianid

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Abstract. Chukars (*Alectoris chukar)* have been widely introduced throughout the world. Their introductions and associated management for sport hunting have the potential to affect native ecosystems in a variety of ways. Our specific objectives were: (1) to document species using water developments designed to benefit chukar populations to determine whether, and at what prevalence, exotic species appear to use, and presumably benefit from, additional watering points; (2) to describe chukar diet with specific reference to cheatgrass and other exotic plant seeds; and (3) to determine whether chukars are a likely vector for dispersal of cheatgrass and/or other plant seeds via passage through the gut. In total, 27 different wildlife species were photographed across all 36 sampled water developments. Three exotic species were photographed to include chukars, rock dove (*Columba livia*), and red fox (*Vulpes vulpes*), with the latter two species photographed at only two and one site respectively. Mean number of species photographed (5.69 ± 1.09) ranged from 1 to 13, but was estimated near 10 after accounting for sampling time. Cheatgrass seed was found in 76.3% of crops and constituted 45.2% of dry weight. Thirteen plants germinated from 503 chukar faecal droppings. We found no evidence of widespread use of water points designed for chukars by other exotic species or dispersal of cheatgrass seed via passage through the gut. Chukars appear (at least initially) benign and they are not likely to be major vectors in plant seed dispersal. Furthermore, chukars could foster localised plant diversity in that they consume large quantities of primarily exotic plant seed and do not show a propensity for dispersal of seeds through faecal droppings.

Introduction

Exotic species can disrupt and threaten native ecosystems in a variety of ways (D'Antonio *et al*. 2001). The impacts of exotic species are varied, complex, and can be influenced by human practices (Keane and Crawley 2002; Myers and Bazley 2003). Both direct and indirect effects are recognised (Roemer *et al*. 2001; Sanders *et al*. 2003). Effects can be further complicated and/or enhanced by continued management practices that promote maintenance or growth of exotic populations for sport, aesthetics, or other reasons. Evaluation of these indirect effects due to continued management is generally lacking in the literature as most research has focused on more apparent impacts.

Chukars (*Alectoris chukar*), medium-sized phasianids native to arid mountainous regions in parts of Asia, Western Europe and the Middle East (Dement'ev and Gladkov 1952; Cramp and Simmons 1980; Ali and Ripley 2001), provide an example of a species with a long history of introduction around the world and of continued management for sport hunting that could affect native ecosystems. Successful attempts to establish chukars outside of native distributions have occurred on at least five continents: Europe (Etchécopar 1955; Lever 1977), Asia (Yanushevich 1966), Australia (Ryan 1906), Africa (Winterbottom 1966), and North America (Long 1981). Additional invasions and present populations occur in arid areas of Hawaii (Walker 1967), New Zealand (Williams 1950), and St Helena Island, Atlantic Ocean (Watson 1966).

The most successful widespread introductions occurred in North America (Long 1981), where chukars were first introduced in 1893 when several pairs were brought to Illinois (Lever 1987). Between 1931 and 1970 over 800 000 birds were released in at least 41 states and six Canadian provinces (Christensen 1970). Original releases were made by private individuals and organisations; however, after 1930 large-scale, government-funded efforts to establish chukars throughout the United States were conducted by state wildlife organisations (Christensen 1996).

By 1954 California, Idaho, Nevada and Washington considered chukars as successfully established (Christensen 1954). Between 1954 and 1968 six additional western states (Arizona, Colorado, Montana, Oregon, Utah and Wyoming) established sufficient populations to consider establishment

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successful and conduct hunting seasons (Christensen 1970). Currently, persistent self-sustaining wild populations in North America are found in the following states and province: Arizona, California, Colorado, Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming, and British Columbia, Canada (Christensen 1996).

Leopold (1938) criticised efforts to establish chukars and foreign game introductions in general as being typified by uninformed and poor science where biologists were stricken with an epidemic he labelled 'Chukaremia'. According to Leopold, this epidemic led game departments to '[rush] pell-mell into full-scale chukar production...' and to avoid informing the public that '... there is no man living who can *predict* the behaviour of an importation' [emphasis in original]. Leopold (1938) primarily focused his ire on the indirect effect of depleted and wasted funds that could have been spent on management of native species rather than any of the typically considered problems (e.g. competition) of exotic species invasions.

Despite his warnings, chukar introductions continued well into the following decades as part of both formalised government programs and private efforts. Chukars now occupy roughly 252 800 km^2 of habitat in North America (Christensen 1996). Large-scale releases into unoccupied habitat have largely stopped; nonetheless, chukars remain a prized game bird and are often propagated and released on game farms by private individuals and organisations throughout the world. Furthermore, and of interest here, are current management practices used to increase distribution and/or density of chukars and the potential ramifications of such activities for native species.

Management of chukars in the United States has generally been limited to water development with particular emphasis placed on the installation of rainwater catchments (guzzlers) to expand populations into new areas (Christensen 1970, 1996; Benolkin 1988). Nevada, for example, has installed over 1500 guzzlers, many of which are designed to primarily benefit chukars (Nevada Department of Wildlife 1999). Guzzlers come in many shapes and sizes, but most recent developments specifically targeting chukar populations are a small model (Fig. 1) designed to collect annual precipitation in a ~1325-L tank located directly beneath the precipitation-collection area (Scott 1994). The tank is designed with a descending slope; as water recedes, smaller animals can walk into the tank and down the slope to drink.

Implications of guzzlers and other water developments (at least in part, an indirect effect of chukar introduction and management) remain poorly evaluated (Devos *et al*. 1997; Rosenstock *et al*. 1999, 2004) and controversial (Broyles 1995; Broyles and Cutler 1999; Rosenstock *et al*. 2001). Concern has been raised that water developments may favour exotic and/or feral species, allowing them to invade otherwise dry areas and out-compete native species adapted to live without free-standing water (Broyles 1995, 1997; Brown 1997; Rosenstock *et al*. 2001).

Additionally, chukars (largely granivorous) have the potential to affect ecosystems due to differential consumption and/or spread of plant seeds. Chukar distribution and success in North America is purportedly linked to cheatgrass (*Bromus tectorum*) (Cox 1999; Walter and Reese 2003), a frequently consumed annual plant considered by some to be the most significant plant invasion in North America (D'Antonio and Vitousek 1992). In less technical forums (but perhaps more widely read), it has even been suggested that chukars aid in dispersal of exotic plant seeds such as cheatgrass (e.g. Peterson 2001).

(*a*)

(*b*)

Fig. 1. (*a*) Small guzzler typical (Scott 1994) of those built in western North America to benefit chukars, with rainwater collection roof over buried shallow tank below. (*b*) Chukars at opening of water tank.

Consequently, we investigated questions related to these potential conservation implications (including indirect effects due to management) of chukars from the framework outlined by Patten *et al*. (2001) wherein the impacts of exotic species are evaluated against null hypotheses of negative effects. Our specific objectives were: (1) to document species using water developments designed for chukars; (2) to describe chukar diet with specific reference to cheatgrass and other exotic plant seeds; and (3) to determine whether chukars are a likely vector for dispersal of cheatgrass and/or other plant seeds via passage through the gut.

Materials and methods

Study area

We evaluated 36 small (~1325 L) guzzlers typical of those designed to benefit chukars (Fig. 1) in five different areas of western Utah located in Box Elder, Juab, and Tooele Counties. These water sources were found on the Cedar Mountains, Tooele County (centred at 40°44′22″N, 112°54′20″W); Fish Springs Range, Juab County (centred at 39°51′36″N, 113°26′19″W); the Grouse Creek/Bovine Mountains and Pilot Mountains, Box Elder County (centred approximately at 41°24′14″N, 113°54′34″W); and the Thomas/Dugway Mountains, Juab County (centred at 39°51′58″N, 113°07′15″W). These 36 guzzlers are similar in design and typical of hundreds scattered throughout Utah, Nevada and other parts of the western United States designed for chukars.

All study areas are encompassed within the Great Basin – characterised by roughly parallel mountain ranges separated by desert basins (Fenneman 1931), hot summers and moderately cold winters (Dice 1943), and a deficiency of precipitation at all seasons (Thornthwaite 1931). Annual precipitation averages 10.2–50.8 cm and daily summer temperature extremes differing between 4.4 and 10°C are common (Christensen 1996). Water sources ranged in elevation from 1320 to 1922 m and were all located within the range of chukar distribution.

Abundant native trees in each area were juniper (*Juniperus* sp.) and pinyon pine (*Pinus edulis*). Native shrubs found include sagebrush (*Artemisia* sp.), Mormon tea (*Ephedra* sp.), Mexican cliff rose (*Cowania mexicana*), curl leaf mountain mahogany (*Cercocarpos ledifolius*), shadscale (*Atriplex* sp.), and others. Grasses and forbs include several native species as well as many exotics. A partial list includes the following: bluebunch wheatgrass (*Elymus spicatum*), cheatgrass, halogeton (*Halogeton glomeratus*), indian rice grass (*Stipa hymenoides*), needle and thread grass (*Stipa comata*), redstem filaree (*Erodium cicutarium*), Russian thistle (*Salsola iberica*), and sandberg bluegrass (*Poa secunda*).

Generalised vegetative communities found in the study areas according to the 2004 South-western Regional Gap Analysis (Lowry *et al*. 2005) include: Great Basin Xeric Mixed and Inter-Mountain Basins Sagebrush Shrubland, Great Basin Pinyon Juniper Woodland, Inter-Mountain Basins Mixed Salt Desert Scrub, Invasive Annual and Perennial Grassland, and Inter-Mountain Basins Semi-Desert Grassland. Additional descriptions of the vegetative component of the study areas were made using 0.125-m^2 quadrats placed at random locations originating from evaluated guzzlers. These analyses showed all sites suffering from cheatgrass invasion as it occupied 6–22% of understorey cover and tied or ranked first in comparison with other plants.

Use of guzzlers

Digital motion-sensing cameras (Camtrakker Inc.®) placed at each guzzler so that approaching animals triggered the camera were used to document with photographic evidence the use of water sources by wildlife species. Cameras were set to operate continuously (both day and night) and were placed a standard 1–2 m from available water to minimise problems associated with differential detection (Cutler and Swann 1999). Cameras were moved sequentially approximately every two weeks to different guzzlers between May and October of each year (2002–05). In 2005, we assigned five cameras to remain on individual separate guzzlers throughout the summer, thereby forcing an extension of sampling time. We moved the remaining cameras ($n = 5$) in sequence. Photographed species were catalogued and results reported (mean number of species per site, total number of species, number of exotic species, etc.) using descriptive statistics.

Additionally, species turnover is reported across sampling sites because of its value as a descriptive measure (Schulter and Ricklefs 1993). The number of species per site was plotted against Julian sampling days and fit to a log-linear regression (integer counts in space–time). Regression with data from all 36 sites created a species-accumulation curve based on sampling time (Magurran 1988; Colwell and Coddington 1994) for our evaluated water developments. This relationship was hypothesised to be asymptotic with values near the asymptote representing a better estimate of mean number of species utilising each guzzler than raw averages due to unequal sampling time.

Dietary analysis

To evaluate chukar diet, we asked hunters to participate before the season and solicited them to save crops from chukars legally harvested during the autumn and winter of 2003–05 from the Cedar, Grouse Creek/Bovine, and Keg Mountains. Additional chukars were collected with shotguns outside of the season during the summer months under approval of the Utah Division of Wildlife Resources. Crops were placed in plastic bags, labelled (location and date), and frozen until analysis. Crop contents were sorted into component parts, weighed on an electronic scale to the nearest 0.00 g, dried in a plant dehydrator, and then reweighed (Walter and Reese 2003). Both frequency and aggregate dry weight data are reported with all information pooled into one sample representing general diet.

We made a single estimate of individual seed weights by collecting and pooling several common seeds pulled from chukar crops, weighing the accumulated seeds (after drying), and then counting them to determine average weight for one seed and estimate the number of seeds found in crops containing given food items. Food items found in <3.0% of crops and constituting <3.0% of dry weight are not reported (Walter and Reese 2003).

Seed dispersal

To determine the potential for chukars to spread seed via passage through the gut, we opportunistically collected chukar faecal droppings from the Cedar Mountains, Grouse Creek/Bovine Mountains, and the Keg Mountains throughout the year (2002 and 2004) in an effort to represent each of the four seasons. Faecal droppings collected in the summer and autumn were collected at watering sites where previous removal had occurred, allowing for accurate estimates of deposition season. We limited our collection of faecal droppings during winter and spring periods to those obviously of recent origin.

Faecal droppings were stored in paper bags in a paper box placed outside over the winter to allow for vernalisation of seeds therein until March of each year at which point they were planted in flats with sterilised soil, placed in a greenhouse, and watered intermittently (Cole *et al*. 1995). Due to concerns about the effectiveness of vernalisation for seeds inside faecal droppings stored outside, half ($n = 121$) of the total faecal droppings collected in 2004 ($n = 242$) were randomly assigned to receive both a cold and wet treatment in greenhouse refrigerators. This treatment involved an initial thorough watering of faecal droppings and their associated greenhouse flats followed by refrigeration at 2°C for five weeks. We laid all faecal droppings on the surface of the soil to simulate natural deposition. We checked the flats periodically and removed any seedlings upon identification. As a cross validation of this technique, 93 faecal droppings (representing summer, autumn, and winter periods) were randomly reserved before germination experiments and screened over soil sieves to look for evidence of viable seeds. Seeds appearing intact and potentially viable were catalogued and recorded.

Results

In total, 27 different wildlife species (Table 1) were photographed across all 36 guzzlers, with 11 (31%) occurring at more than 10% of guzzlers. Fourteen of the species (54%) were birds, eleven (42%) mammals, and one reptile (4%). Mourning dove (*Zenaida macroura*), cottontail (*Sylvilagus* sp.), bobcat (*Lynx rufus*), wood rat (*Neotoma* sp.), chukar, and rock wren (*Salpinctes obsoletus*) were the most commonly photographed species and all occurred at more than 50% of guzzlers sampled. Three exotic species were photographed – chukars, rock dove (*Columba livia*), and red fox (*Vulpes vulpes*) – with the latter two species photographed at only two and one site respectively. Mean number of species photographed at guzzlers was 5.69 ± 1.09, with a range from 1 to 13.

Estimated average number of species utilising a given small guzzler after accounting for sampling time of up to 100 Julian days was near 10 (Fig. 2) with the log-linear relationship meaningful and significant ($R^2 = 0.46$, $P < 0.001$). Lower and upper 95% confidence limits were near 8 and 12 respectively. Gamma richness (27) of our sample was described by α (5.69) and β (0.13) richness with sampling units of 36 and the equation $\gamma = 36\alpha\beta$, where β is equal to the inverse of the average number (7.48) of guzzlers from which detections of each species were made (Schulter and Ricklefs 1993).

Fourteen food items met or exceeded 3.0% of total dry weight or were found in >3.0% of examined crops. Cheatgrass seed was found in 76.3% of crops and constituted 45.2% of dry weight (Table 2). Red-stem filaree, an exotic forb, was found in 6.5% of crops and equaled 1.3% of dry weight. Other common food items originating from native species included ricegrass seed, hawksbeard (*Crepis acuminata*) seed, and arthropods (mostly Orthoptera). Seeds accounted for 81% of dry mass, confirming the granivorous nature of chukars. Grass leaves (48.4% frequency and 3.0% dry weight) were largely suspected to be those of cheatgrass on the basis of leaf morphology.

Estimated numbers of seeds per crop for birds consuming given food items ranged from 79 sunflower (*Helianthus annuus*) seeds to 900 spurge (*Euphorbia* sp.) seeds; the estimated average number of cheatgrass seeds per crop was 522 (Table 2). Thus, our sample of 93 crops was estimated to contain 37 041 cheatgrass seeds, 15 680 hawksbeard seeds, 5967 ricegrass seeds, 5441 spurge seeds, 1167 red-stem filaree seeds, and

Table 1. List of species photographed across 36 small-model guzzlers in western Utah
Exotic species are indicated with an asterisk. The red fox is considered exotic in the study area (Kamler and Ballard 2002)

Species	Scientific name	No. of sites	Frequency
Mourning dove	*Zenaida macroura*	25	0.69
Cottontail	*Sylvilagus* sp.	22	0.61
Bobcat	*Lynx rufus*	21	0.58
Chukar*	*Alectoris chukar*	19	0.53
Woodrat	*Neotoma* sp.	19	0.53
Rock wren	*Salpinctes obsoletus*	18	0.50
Whitetail antelope squirrel	*Ammospermophilus leucurus*	15	0.42
Mouse	*Peromyscus* sp.	13	0.36
Western spotted skunk	*Spilogale gracilis*	10	0.28
House finch	*Carpodacus mexicanus*	6	0.17
Coyote	*Canis latrans*	4	0.11
Black-throated sparrow	*Amphispiza bilineata*	3	0.08
Black-tailed jackrabbit	*Lepus californicus*	3	0.08
Lark sparrow	*Chondestes grammacus*	3	0.08
Western meadowlark	*Sturnella neglecta*	3	0.08
Badger	*Taxidea taxus*	3	0.08
Black-billed magpie	*Pica hudsonia*	2	0.06
Unknown passerine	–	2	0.06
Rock dove*	*Columba livia*	2	0.06
Striped skunk	*Mephitis mephitis*	2	0.06
Gopher snake	*Pituophis melanoleucus*	1	0.03
Red fox*	*Vulpes vulpes*	1	0.03
Blue-grey gnatcatcher	*Polioptila caerulea*	1	0.03
Lazuli bunting	*Passerina amoena*	1	0.03
Gray fox	*Urocyon cinereoargenteus*	1	0.03
Sage thrasher	*Oreoscoptes montanus*	1	0.03
Kit fox	*Vulpes macrotis*	1	0.03

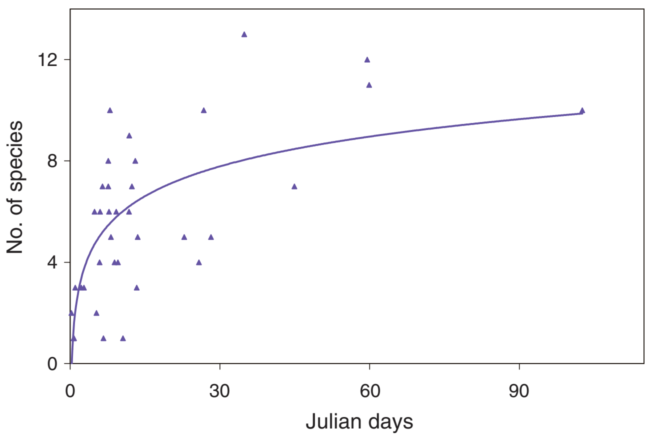

Fig. 2. Shown here is the number of species photographed at guzzlers scaled to sampling time (95% confidence bands also shown) and resultant log-linear function ($y = 1.70\ \ln(x) + 2.02$) that fits these data ($R^2 = 0.46$, $P < 0.001$).

632 sunflower seeds. Given these results, we are confident that cheatgrass seed was consumed and available for passage via the gut and subsequent germination from faecal droppings.

Thirteen plants germinated from 503 chukar faecal droppings to include red-stem filaree, halogeton, littlepod false flax (*Camelina microcarpa*), and a kochia (*Kochia* sp.) (Table 3). Cheatgrass did not germinate from any of the flats. Screening of faecal droppings ($n = 93$) to look for evidence of viable seeds revealed similar results, with detection of only three viable red-stem filaree seeds. Results were similar for faecal droppings given a cold–wet treatment in a refrigerator and those only vernalised outside over the winter and early spring.

Discussion

Criticism of guzzlers and water developments in general has intensified in recent years both with respect to their efficacy (Campbell 1960; Burkett and Thompson 1994; Broyles 1995; Rosenstock *et al*. 1999) and the potential for deleterious effects (Broyles 1997; Rosenstock *et al*. 1999; Andrew *et al*. 2001). Of specific concern here are suggestions that guzzlers may facilitate expansion of non-target exotic and/or feral species (Broyles 1995, 1997; Brown 1997). Our results do not validate this concern with respect to guzzlers developed for chukars in western Utah as only two exotic and/or feral species (other than targeted chukars) were photographed using guzzlers. Red foxes were photographed at one guzzler on one of the five study areas whereas rock doves were photographed at two different guzzlers in one of the five study areas.

Twenty-three of the 26 (88%) identifiable species detected were natives (Table 1), with a raw average of 5.69 species utilising each guzzler. Our hypothesis of an asymptotic relationship between species counts and sampling time was not dismissed ($R^2 = 0.46$, $P < 0.001$) and the resulting plot (Fig. 2) is suggestive of a mean number of species per guzzler somewhere near 10 (95% confidence limits near 8 and 12). Species turnover was relatively low (0.13) across sampling units, indicative of a small and somewhat steady suite of species utilising guzzlers designed for chukars in western Utah. This concept is further strengthened in that only 11 species (Table 1) were photographed at >10% of guzzlers. Interestingly, raptors are missing from our list despite their well documented use of other styles of water developments in western North America (Rosenstock *et al*. 2004). Explanations could include a failure to recognise small-model guzzlers as a source of water, difficulty in use of small models, or preferential use of other sources (springs, other water developments).

Our results confirm the granivorous nature of chukars (Weaver and Haskell 1967; Oakleaf and Robertson 1971; Cole *et al*. 1995), with cheatgrass seed the predominant food item in North America (Christensen 1996). Cheatgrass seed was found in 87.5% of autumn crops collected in eastern Oregon (Walter and Reese 2003), 56.1% of late summer and early autumn crops in Nevada (Alcorn and Richardson 1951), 39–64% of Washington crops dependent on season (Galbreath and Moreland 1953), and 69% of an annual sample in California

Table 2. Food items found in Chukar crops from western Utah ($n = 93$)
Exotic species are indicated with an asterisk

Crop item[A]	Scientific name	Frequency (%)	Dry weight (%)	Average weight (g)[B]	Estimated no. of seeds per crop[B]
Cheatgrass seeds*	*Bromus tectorum*	76.3	45.2	1.21	522
Grass leaves	Various	48.4	3.0	0.13	n/a
Grit	n/a	46.2	1.4	0.06	n/a
Ricegrass seeds	*Stipa hymenoides*	36.6	21.0	1.17	175
Arthropods	Arthropoda spp.	34.4	5.5	0.33	n/a
Hawksbeard seeds	*Crepis acuminata*	25.8	10.1	0.80	661
Bulbous bluegrass bulbs	*Poa bulbosa* L.	8.6	0.90	0.21	n/a
Sunflower seeds	*Helianthus annus*	8.6	2.0	0.48	79
Onion bulbs	*Allium* sp.	6.5	2.6	0.82	n/a
Spurge seeds	*Euphorbia* sp.	6.5	1.4	0.45	900
Red-stem filaree seeds*	*Erodium cicutarium*	6.5	1.3	0.39	193
Sage brush galls	*Artemisia* sp.	4.3	1.1	0.53	n/a
Unidentified	n/a	21.5	2.0	0.19	n/a
Other roots	n/a	3.2	<0.1	0.12	n/a

[A]Only items occurring in >3.0% of sample or constituting >3.0% of total dry weight are included.
[B]Average of contents for crops containing given food items.

Table 3. Results of germination experiments from Chukar faecal droppings
Exotic species are indicated with an asterisk. BE = Box Elder County; CM = Cedar Mountains; KM = Keg Mountains

Year collected	Area(s)	Season	Faecal droppings planted	Plants germinated	No.
2002	CM	Summer	37	*Erodium cicutarium**	2
2003	CM, KM	Summer	72	*Kochia* sp.*	2
				*Erodium cicutarium**	3
2003	BE, KM	Fall	70	*Halogeton glomeratus**	1
2003–04	KM	Winter	37	–	0
2004	KM	Spring	45	–	0
2004	CM, KM	Fall	208	*Camelina microcarpa**	2
				*Erodium cicutarium**	3
2004	KM	Winter	34	–	0
Total	CM, KM, BE	4 seasons	503	Four different species	13

(Zembal 1977). Similar results with respect to the prevalence of seeds from ricegrass, red-stem filaree, sunflower, etc. have also been reported (Christensen 1952, 1970; Weaver and Haskell 1967).

Most dietary studies involving chukars in North America report utilisation of cheatgrass in seed and/or leaf form (e.g. Churchwell *et al.* 2004). Hence, some authors (Cox 1999; Walter and Reese 2003) have suggested an apparent functional link between the establishment of chukars and cheatgrass. Interestingly, however, cheatgrass specifically has not shown up in dietary studies from Hawaii (Cole *et al*. 1995) or Eurasia (Oakleaf and Robertson 1971; Alkon *et al*. 1985; Dayani 1986; Naifa 1995), although these studies report high reliance on seeds of both native and exotic grasses and forbs. Furthermore, chukars have not followed cheatgrass expansion across North America into areas such as the Midwest or extreme south-west and thus their distribution is contingent on other factors.

We caution against a suggestive link between chukar distribution in North America and cheatgrass based solely on the plant's documented frequency or aggregate weight in crop contents – particularly in the absence of data documenting important factors other than utilisation (e.g. preference, fitness, etc. of chukars eating cheatgrass) and given that chukars apparently maintain themselves without it (Oakleaf and Robertson 1971; Alkon *et al*. 1985; Dayani 1986; Cole *et al*. 1995; Naifa 1995). Frequent utilisation of a given resource is not necessarily the same as a functional link to the establishment of another species.

Seed counts or estimates per crop are lacking in the literature; nonetheless, Alcorn and Richardson (1951) reported over 900 cheatgrass seeds in one crop and over 2000 red-stem filaree seeds in another. Seed weights confirm observations by others (Dayani 1986; Walter and Reese 2003) that chukars appear to be opportunistic foragers willing to consume a wide variety of food items, but relying on a small subset to comprise the bulk of their diet (Dayani 1986; Walter and Reese 2003) composed largely of grass and forb seeds with particular emphasis on cheatgrass seed in North America (Christensen 1996).

Cole *et al*. (1995) conducted similar germination experiments from chukar faecal droppings collected in Hawaii. Results included germination of 115 seeds from eight plant species. Native species outnumbered exotics five to one, with a general conclusion that exotic game birds in Hawaii served (at least superficially) as ecological surrogates for extinct and endangered indigenous species such as the nene (*Branta sandvicensis*) in the distribution of native plant seed.

Differences between our results are likely attributable to digestibility of respective food items – cheatgrass, in particular, has a relatively large and soft seed easily digested in the gizzard. Faecal droppings screened over soil sieves generally contained plant material beyond any recognition to plant part, or specific taxa indicative of relatively complete digestion. The plants that did germinate (Table 3) have small and/or tough seeds more likely to pass through the digestive tract. Red-stem filaree, six of 13 (46%) germinated seeds, in particular, has a small seed protected by a sharp and tough sheath. These findings suggest that chukars have developed the ability to process most seeds and the probability of viable seed passage is low for most plants. Plants most likely to be spread by chukars are those with tough and/or relatively small seeds. Plants with large and soft seeds similar to those of cheatgrass are unlikely to be transported by chukars.

The history of cheatgrass in North America, albeit similar to that of chukars, is unrelated. Cheatgrass first appeared in North America in the late 1800s, originating from multiple introductions (Upadhyaya *et al*. 1986; Novak and Mack 2001), and quickly spread throughout the Intermountain West (Mack 1981). Considered the quintessential invader (Novak and Mack 2001), cheatgrass is the dominant plant on at least 200 000 km^2 in the Intermountain West (Mack 1989) and a potential dominant on over 250 905 km^2 (Pellent and Hall 1994). Cheatgrass-dominated communities are likely a permanent part of the landscape in some areas (Knapp 1992).

Not favoured by other rangeland birds (Goebel and Berry 1976) and palatable to grazing animals only during a short window (Cook and Harris 1968; Upadhyaya *et al*. 1986; Mayland *et al*. 1994), cheatgrass quickly invades disturbed areas (Evans and Young 1970), out-competing native species through a variety of adaptations (Hironaka 1961; Chatterton 1994; Nasri and Doescher 1995). Problems associated with invasion of cheatgrass include increased fire cycles (Stewart and Hull 1949; Savage *et al*. 1969; Billings 1994), reduced soil moisture (Hulbert 1955), elimination of native perennials (Savage *et al*.

1969; Whisenant 1990), and other ails (see Billings 1990, 1994; Zouhar 2003 for a more thorough enumeration of problems). Some (D'Antonio and Vitousek 1992) consider cheatgrass and other exotic plant invasions to be large and serious enough to threaten disruptions of global climate.

Chukars have certainly not slowed the spread of cheatgrass in western North America, which has happened in spite of increased distribution and density of chukars over the last 50 years. Prolific seed production with natural seeding rates as high as 70.8 million seeds per acre (Hull and Pechanec 1947) may allow cheatgrass to overwhelm granivores. Nonetheless, chukars could help foster localised plant diversity through selective consumption of large quantities of cheatgrass seed in heavily utilised areas. Research shows, for example, that cheatgrass density increases in the absence of utilisation by granivores (Pyke and Novak 1994). This idea, however, has not been tested and could serve as a question for future research.

Although we concur with Patten *et al*. (2001) that exotic species should be evaluated under the null hypothesis of negative effects, we caution against *de facto* assignment of specific problems in the absence of scientific inquiry. Chukars may pose undefined conservation implications to western North American ecosystems, but recognition of negative effects has not been made. We found no evidence of widespread use of guzzlers designed for chukars by other exotic species or dispersal of cheatgrass seed via passage through the gut (contra Peterson 2001). Chukars appear (at least initially) to fall into Williamson and Fitter's (1996) second tier of the 'rule of tens' – i.e. those that become established but not problematic. Furthermore, chukars may be beneficial in that they consume vast quantities of primarily exotic plant seed and do not show a propensity for dispersal of seeds through faecal droppings. Management of western North American rangelands for chukars does not foster cheatgrass dispersal nor significant exotic animal use of small-model water developments. Chukars are least likely to spread seeds that are large and soft and most likely to spread small, tough seeds via passage through the gut.

Risks associated with chukar introductions and continued management practices in North America appear relatively low. Nonetheless, there are a myriad of potential impacts with any exotic species invasion and these results should not be considered conclusive. Other potential implications such as dispersal of seed in their feathers, role as a food resource for avian and mammalian predators, direct or indirect competition with native species, the potential for alteration in native species diversity as a result of water development, and others are candidates for future investigation. To date, however, chukars appear benign, if not beneficial, to western North American ecosystems.

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