



Johnson, W. P., P. M. Schmidt, and D. P. Taylor. 2014. Foraging flight distances of wintering ducks and geese: a review. *Avian Conservation and Ecology* 9(2): 2. <http://dx.doi.org/10.5751/ACE-00683-090202>

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Research Paper

## Foraging flight distances of wintering ducks and geese: a review

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**ABSTRACT.** The distance covered by foraging animals, especially those that radiate from a central area when foraging, may affect ecosystem, community, and population dynamics, and has conservation and landscape planning implications for multiple taxa, including migratory waterfowl. Migrating and wintering waterfowl make regular foraging flights between roosting and feeding areas that can greatly impact energetic resources within the foraging zone near roost sites. We reviewed published studies and gray literature for one-way foraging flight distances (FFDs) of migrating and wintering dabbling ducks and geese. Thirty reviewed studies reported FFDs and several reported values for multiple species or locations. We obtained FFD values for migration ( $n = 7$ ) and winter ( $n = 70$ ). We evaluated the effects of body mass, guild, i.e., dabbling duck or goose, and location, i.e., Nearctic or Palearctic, on FFDs. We used the second-order Akaike's Information Criterion for model selection. We found support for effects of location and guild on FFDs. FFDs of waterfowl wintering in the Nearctic ( $7.4 \pm 6.7$  km, mean  $\pm$  SD;  $n = 39$  values) were longer than in the Palearctic ( $4.2 \pm 3.2$  km;  $n = 31$  values). The FFDs of geese ( $7.8 \pm 7.2$  km, mean  $\pm$  SD;  $n = 24$  values) were longer than FFDs of dabbling ducks ( $5.1 \pm 4.4$  km, mean  $\pm$  SD;  $n = 46$  values). We found mixed evidence that distance flown from the roost changed, i.e., increased or decreased, seasonally. Our results can be used to refine estimates of energetic carrying capacity around roosts and in biological and landscape planning efforts.

### Distances parcourues pour la recherche alimentaire par les oies et les canards hivernants : une synthèse.

**RÉSUMÉ.** La distance parcourue par les animaux aux fins de recherche alimentaire, particulièrement chez ceux qui rayonnent à partir d'un point central, peut influencer l'écosystème, la biocénose, ainsi que les dynamiques de population. Pour beaucoup de taxons incluant les anatidés migrants, la distance parcourue a également des implications sur la conservation et la planification des paysages. Les vols réguliers des anatidés (migrants ou hivernants) entre l'espace de nourrissage et de repos, peuvent impacter lourdement les ressources énergétiques au sein de la zone de nourrissage proche des sites de repos. Nous avons examiné les études et la littérature grise concernant les distances des allés vers les sites de nourrissage (DASN) des barboteurs et des oies migrants et hivernants. Trente études examinées ont indiqué les DASN dont un certain nombre ont mentionné des valeurs pour plusieurs espèces ou lieux. Nous avons obtenu des valeurs de DASN pour la migration ( $n=7$ ) et pour l'hiver ( $n=70$ ). Nous avons évalué les effets de la masse corporelle, guild, i.e., barboteur ou oie, et lieu, i.e., Néarctique ou Paléarctique, sur les DASN. Nous avons utilisé comme modèle de sélection le Critère d'Information d'Akaike de second ordre. Nous avons trouvé des effets de lieu et guild sur les DASN. Les DASN des anatidés hivernant dans le Néarctique ( $7.4 \pm 6.7$ km, moyenne  $\pm$  ET;  $n = 39$  valeurs) étaient plus longues que dans le Paléarctique ( $4.2 \pm 3.2$  km;  $n = 31$  valeurs). Les DASN des oies ( $7.8 \pm 7.2$  km, moyenne  $\pm$  ET;  $n = 24$  valeurs) étaient plus longues que les DASN des barboteurs ( $5.1 \pm 4.4$  km, moyenne  $\pm$  ET;  $n = 46$  valeurs). Nous avons constaté que les distances parcourues à partir des sites de repos varient, i.e., augmentent ou se réduisent en fonction de la saison. Nos résultats peuvent être utilisés pour améliorer les estimations des capacités de charges énergétiques autour des zones de repos et dans les efforts de planifications biologiques et paysagés.

**Key Words:** *commute flights; dabbling ducks; field feeding; functional unit; geese; refuging; roost-feeding-area complex; winter movements*

## INTRODUCTION

The distance covered by foraging animals, especially those that radiate from a central area to forage, i.e., central place foragers (Hamilton and Watt 1970), may affect daily energy expenditure of individuals (Baveco et al. 2011) along with ecosystem, community, and population dynamics (Greenleaf et al. 2007, Rainho and Palmeirim 2011). It also has conservation and landscape planning implications for multiple taxa, including bees (Walther-Hellwig and Frankl 2000, Greenleaf et al. 2007), bats (Rainho and Palmeirim 2011), colonial nesting waterbirds (Bryan et al. 2012), and migratory waterfowl (Cox and Afton 1996, Guillemain et al. 2008). Migrating and wintering waterfowl, in

particular, make regular foraging flights between roosting and feeding areas (e.g., Newton and Campbell 1973, Tamisier 1974, 1976, Baldassarre and Bolen 1984, Owen and Black 1990), activity that can greatly affect availability of energetic resources within the foraging zone (Frederick et al. 1987, Pearse et al. 2010).

Foraging flights have been documented in regions where agriculture grains, sugar beets (*Beta vulgaris vulgaris*), potatoes (*Solanum tuberosum*), and other food crops are grown in proximity to concentrations of migrating and wintering waterfowl (Newton and Campbell 1973, Baldassarre and Bolen 1984, Fleskes et al. 2003, Skyllberg et al. 2005). Although foraging flights are common in waterfowl that exploit agricultural crops, such as

dabbling ducks and geese (Baldassarre and Bolen 1984, Vickery and Gill 1999), waterfowl also make foraging flights to browse on pasture, meadow, and submerged aquatic vegetation, and to feed in freshwater wetlands and coastal waters (Morton et al. 1989, Howerter 1990, Vickery and Gill 1999, Merkel et al. 2006). Distances flown between roost sites and foraging areas may be influenced by the proximity of habitats (Frederick et al. 1987, Cox and Afton 1996, Davis and Afton 2010), food availability (Cox and Afton 1996, Gill 1996, Link et al. 2011), disturbance (Austin and Humburg 1992, Moon 2004, Fleskes et al. 2005), type of foraging habitat (Hill and Frederick 1997), temperature/weather (Jorde et al. 1983, Baldassarre and Bolen 1984, Legagneux et al. 2009), body size (Mini 2012), social status of individual birds (Morton et al. 1989, Cox and Afton 1996), and other factors. Legagneux et al. (2009) noted that wintering dabbling ducks in North America appear to make longer foraging flights than those in Europe and suggested this may be related, in part, to the abundance of waterfowl concentrated at wintering areas; they speculated that longer foraging flights might be associated with larger bird densities, high demand for and high use of food resources caused by those densities, and also potential habitat characteristics such as distances between roost sites and feeding sites.

The secure roosting/loafing sites and surrounding feeding areas utilized by migrating and wintering waterfowl are termed functional units (Tamisier 1974, Tamisier and Tamisier 1981, Tamisier 1985, Guillemain et al. 2002, Herring and Collazo 2005) or roost-feeding-area complexes (Skjellberg et al. 2005). In formulating the functional-unit concept, Tamisier (1974, 1976, 1978-1979, 1985) called for incorporating feeding habitats and other potentially important areas within the foraging flight distance (FFD) of roosts into management and conservation plans for migrating and wintering waterfowl. Planning focused at the functional-unit scale or within the FFD has multiple conservation implications. Food resources within functional units can be estimated to gauge energetic carrying capacity (Pearse et al. 2010). Predictions about spatial and seasonal resource use within functional units are consistent with “refuging” theory (Hamilton and Watt 1970), which posits that foods closer to roost sites will be utilized and depleted first, forcing ducks and geese to radiate further from roosts to meet their energetic demands as the season progresses (Frederick et al. 1987, Cox and Afton 1996, Gill 1996). Energy expenditure and daily energy budgets are affected by distance of foraging flights (Pearse et al. 2010), as is the giving-up density, or the point at which food depletion makes it no longer profitable to feed in a given field (van Gils and Tijssen 2007). Likewise, crop damage by waterfowl may be alleviated by locating vulnerable crops farther from roost sites, even if still within the FFD of waterfowl (Sugden 1976, Amano et al. 2007, Baveco et al. 2011). Landscape carrying capacity within functional units may be affected by location of wind turbines, towers, and other tall infrastructure in or near foraging sites, if their placement leads to avoidance of areas (Larsen and Madsen 2000, Kuvlesky et al. 2007, Rees 2012); placement of wind turbines, towers, or other tall infrastructure between roost and foraging sites may also lead to waterfowl mortality (Bevanger 1994, Drewitt and Langston 2006). Thus, understanding the zone of waterfowl use around roost sites may improve waterfowl management strategies (Gill 1996, Amano et al. 2007, Bregnballe et al. 2009) and factor into

landscape conservation designs, including plans for wetland complexes (Lovvorn and Baldwin 1996, Cox and Afton 1997, Madsen et al. 1998, Riley et al. 2005, Pearse et al. 2011) and plans intended to minimize anthropogenic impacts to waterfowl (Larsen and Madsen 2000).

Our objectives were to review literature for one-way FFDs of migrating and wintering dabbling ducks and geese, and evaluate factors hypothesized to influence FFDs. We expected FFDs of waterfowl to be influenced by guild, waterfowl density, roost wetland size, the juxtaposition and availability of different habitats, and interactions among these factors.

## METHODS

### Literature review

We assessed peer-reviewed studies and gray literature for one-way FFDs in kilometers of spring/fall migrating and wintering dabbling ducks and geese. Examples of gray literature include conference proceedings and dissertations. The search was performed using species accounts (e.g., Poole 2005), journal search engines including BioOne, Google Scholar, JSTOR, and the Searchable Ornithological Research Archive; publisher-based search engines including ScienceDirect, SpringerLink, Taylor & Francis Online, and Wiley Online Library; and by assessing citations in waterfowl texts (e.g., Owen and Black 1990). Terms used in search engines in combination with “duck,” “goose,” or “waterfowl” included [commute], [core area], [fall diet], [fall movement], [flight], [feeding flight], [field feed], [flight distance], [foraging flight], [functional unit], [home range], [movement], [nonbreeding], [spring diet], [spring movement], [winter diet], [winter movement], and [winter roost]; these search terms were often used in combination with each another. When authors contributing FFD information were documented, additional searches were conducted using their names. Web pages of authors contributing FFD information were accessed, if available, to examine publication lists. We restricted our review to dabbling ducks (*Anas* spp.) and geese, and to studies conducted in the Nearctic and Palearctic.

We selected studies reporting information on individuals, e.g., marked birds or flocks moving from roost sites to foraging sites, and studies reporting distance of known foraging fields from known roosting sites. Because FFD information was ancillary to the primary objective of most studies we reviewed, informative tests on sex, age, roost size, forage habitat type, or seasonal effects, i.e., changes in distances flown as seasons progress (Hamilton and Watt 1970, Cox and Afton 1996), were seldom performed. When significant differences between age cohorts or year were reported (e.g., Cox and Afton 1996, Link et al. 2011), these FFD values were considered to be independent and were included in our review and subsequent analyses. We used mean, or median if the mean was not available, FFD values reported in studies, not values representing the upper range or maximum FFD for individuals or flocks. We excluded FFD values from Tamisier and Tamisier (1981) because they believed their FFD results were not representative of birds in the study area because of unexpected biases in study design.

We coded FFD values as winter or migration based on how they were described in the literature. FFD values coded as migration

were primarily from observations on staging areas. FFD values coded as winter generally occurred on terminal winter locations, but may have extended into the fall and spring (e.g., Patterson et al. 1989, Hill and Frederick 1997). Other information pulled from studies included (1) major purpose(s) of the study; (2) how birds were followed, i.e., telemetry, unmarked, or color marked; (3) general foraging habitat, i.e., wetland, rice (*Oryza sativa*), or terrestrial, which included high marsh, pasture, grassland, and cropland other than rice; (4) information concerning seasonal effects; and (5) waterfowl density.

### Statistical analysis

Because of the small number of values ( $n = 7$ ) representing migration, we only included winter values in the analysis. Although we hypothesized that FFD would be influenced by several factors, many could not be enumerated from the available studies. The habitat type used by birds at foraging sites, roost site characteristics, and local bird densities were not consistently reported. We assumed these parameters would show similar trends within geographic regions (in accordance with Legagneux et al. 2009); thus, we evaluated the potential influence of general geographic location on FFD. We evaluated the effects of body mass in grams, guild, i.e., dabbling duck or goose, and location, i.e., Nearctic or Palearctic, on FFD using linear regressions and model likelihood estimates to relate explanatory variables to FFD. Body mass values used in our analysis came from FFD studies when available; when not available, body mass was based on published values for wintering waterfowl and was location and subspecies specific (Appendix 1). We expected the FFD of waterfowl would be longer in the Nearctic (Legagneux et al. 2009), would be longer for geese, and would increase with increasing body mass because of the increased efficiency and decreased energetic costs of sustained, forward flight associated with increasing body size (Schmidt-Nielsen 1972, Harrison and Roberts 2000, Greenleaf et al. 2007). Further, we expected that FFD would vary by body mass, guild, and location (i.e., the interaction between mass and location and the interaction between guild and location).

We used an information theoretic approach to evaluate the relative fit of our suite of potential models (Burnham and Anderson 2002). We used the second-order Akaike's Information Criterion ( $AIC_c$ ) for model selection (Burnham and Anderson 2002). We considered models less than or equal to 2  $AIC_c$  units as competitive models and considered models greater than 2  $AIC_c$  units as unlikely representations of the data. We conducted analyses using the `lm` function in the base R package (R Development Core Team 2012) and used  $AIC_c$  function in the `qPCR` package, version 1.3-7 (Spiess 2012). To assist with interpretation of the compiled data, we also present summary statistics related to how birds were followed, general foraging habitat types, and seasonal differences in FFD; the descriptive statistics do not include the FFD value that came from an unpublished source.

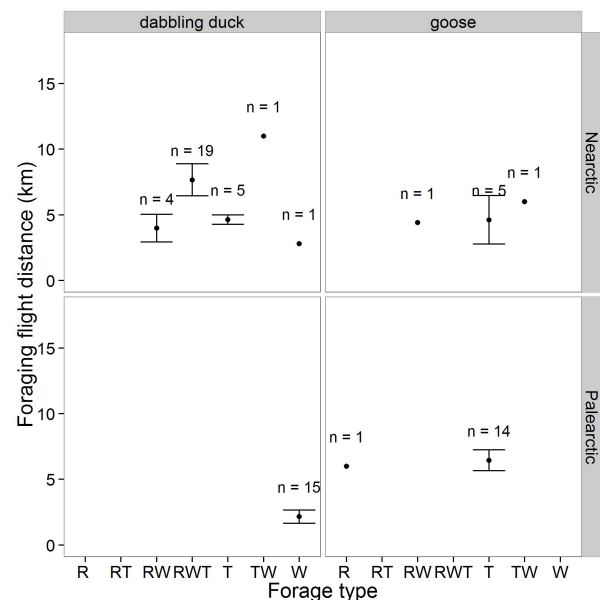
### RESULTS

Although many studies reported casual observations of FFD, values often represented the far or extreme distance birds were observed to forage from roost sites, or the general distances that waterfowl were thought to be flying to feed; only 30 reviewed

studies reported mean FFD values (Table 1). Several of these studies reported values for multiple species or multiple locations; in total, we had 70 values for winter. One FFD value came from unpublished information and did not include a habitat association. Likely because of the crepuscular feeding tendency of wintering dabbling ducks and subsequent difficulty in observing them (McNeil et al. 1992), 83% of FFD values for these ducks were telemetry based. For geese, which are primarily diurnal foragers and easier to follow in flight, only 38% of values involved telemetry.

Based on habitat descriptions in reviewed studies, 59% of the 69 FFD values, excluding unpublished information, were associated with only one general habitat type; 13% were associated with two habitat types, e.g., wetlands and terrestrial, and 16% were associated with three habitat types (Table 1, Fig. 1). All FFD values from the Palearctic ( $n = 30$ ) were associated with a single habitat type; in contrast, only 28% of FFD values from the Nearctic ( $n = 39$ ) were associated with a single habitat type, the remainder being associated with multiple habitat types. Terrestrial foraging habitats were associated with 92% of the 24 FFD values for wintering geese (Table 1, Fig. 1). All goose FFD values associated with rice involved Greater White-fronted Geese (*Anser albifrons*), and these values came from both the Palearctic and Nearctic. All dabbling duck FFD values from the Palearctic ( $n = 15$ ) were associated with wetlands only. In contrast, for dabbling ducks in the Nearctic, 83% of 30 FFD values were associated with wetlands, 87% were associated with terrestrial habitats, and 73% were associated with rice, with 80% being associated with two or more of these habitat types.

**Fig. 1.** Mean foraging flight distance (km), standard errors, and sample sizes for wintering waterfowl by Guild (dabbling duck, goose), Location (Nearctic, Palearctic), and Forage Type (T = terrestrial, which included high marsh, pasture, grassland, or cropland other than rice [*Oryza sativa*]; W = wetland, and R = rice).



**Table 1.** Distances flown (flight distance) between roost site to feeding site for waterfowl during migration and winter. When significant differences between age cohorts or year were reported, we included them as independent foraging flight distance values in our review and subsequent analyses. Scientific names for all species listed in Appendix 1.

Species (subspecies)	General location <sup>†</sup>	Year/How Followed <sup>‡</sup>	Survey period <sup>§</sup>	Mean flight distance	Forage type <sup>#</sup>	Source
Greylag Goose	Ume River Delta, Umeå, Sweden	2004/U	S	4.8 <sup>l</sup>	T	Skyllberg et al. 2005
	NE Scotland	1984-86/U	W	3.4 <sup>¶</sup>	T	Patterson et al. 1989
	NE (L. Strathbeg) Scotland	1977-86/U	W	10.4 <sup>¶</sup>	T	Bell 1988
	NE (Slains L.) Scotland	1977-86/U	W	5.8 <sup>¶</sup>	T	Bell 1988
	NE (Skene L.) Scotland	1977-86/U	W	5.8 <sup>¶</sup>	T	Bell 1988
	NE (Dinnet L.) Scotland	1977-86/U	W	14.2 <sup>¶</sup>	T	Bell 1988
Pink-Footed Goose	NE Scotland	1984-86/U	W	4.4 <sup>¶</sup>	T	Patterson et al. 1989
	Holkham NNR, Norfolk, England	1990-91/U	W	8.0 <sup>#</sup>	T	Vickery et al. 1997
	NE Scotland	1987-88/T	W	4.8	T	Giroux and Patterson 1995
	NE (L. Strathbeg) Scotland	1977-86/U	W	3.9 <sup>¶</sup>	T	Bell 1988
Bean Goose	NE (Slains L.) Scotland	1977-86/U	W	4.1 <sup>¶</sup>	T	Bell 1988
	Ume River Delta, Umeå, Sweden	2004/U	S	1.4 <sup>l</sup>	T	Skyllberg et al. 2005
Greater White-fronted Goose	SW Skåne, Sweden	1977-80/C	W	5.0	T	Nilsson and Persson 1984
	California Central Valley, USA	1987-90/T	W	32.5	R/T	Ackerman et al. 2006
(tule)	California Central Valley, USA	1998-00/T	W	24.8	R/T	Ackerman et al. 2006
	L. Izunuma-Uchinuma, Japan	1997-99, 02/U	W	6.0 <sup>l</sup>	R	Shimada 2003
(Greenland)	Delevan NWR, California, USA	1995-96/T	W	4.4 <sup>††</sup>	R/W	Hobbs 1999
	Holkham NNR, Norfolk, England	1990-91/U	W	8.0 <sup>#</sup>	T	Vickery et al. 1997
Snow Goose (greater)	Delmarva Peninsula, USA	1990-91/T	W	6.0	T/W	Hill and Frederick 1997
Snow Goose (lesser)	C. Missouri River Valley, USA	1983 and 84/U	W	11.5	T	Davis et al. 1989
Dark-bellied Brent	Holkham NNR, Norfolk, England	1990-91/U	W	5.0 <sup>#</sup>	T	Vickery et al. 1997
	Missouri, USA	1985-87/T	W	2.2 <sup>‡‡</sup>	T	Austin 1988
Canada Goose	Maryland, USA	1984-86/ C,T	W	1.2	T	Harvey et al. 1998
	Willamette Valley, Oregon, USA	2007-09/T	W	3.0	T	Mini 2012
(dusky)	Willamette Valley, Oregon, USA	2007-09/T	W	5.2	T	Mini 2012
Cackling Goose	Willamette Valley, Oregon, USA	2007-09/T	W	5.2	T	Mini 2012
	NW California, USA	2003-04/U	S	15.5 <sup>¶</sup>	T	Mini and Black 2009
(Aleutian)	Humbolt Bay, California, USA	2003-04/U	S	7.0 <sup>¶</sup>	T	Mini and Black 2009
(Aleutian)	Humbolt Bay, California, USA	2007/U	S	23.0	T	Spragens 2010
Barnacle Goose	N. (Lauwersmeer) Netherlands	2008/T	S	2.0 <sup>l</sup>	T	Si et al. 2011
	Solway Firth, Great Britain	1972-84/U	W	7.5 <sup>§§</sup>	T	Owen et al. 1987
Mallard	N. (Seine) France	2002-03/T	W	0.7	W	Legagneux et al. 2009
	N. (Seine) France	2003-04/T	W	1.1	W	Legagneux et al. 2009
	C. (Brenne) France	2001-02/T	W	0.5	W	Legagneux et al. 2009
	C. (Brenne) France	2002-03/T	W	1.2	W	Legagneux et al. 2009
	C. (Brenne) France	2003-04/T	W	1.3	W	Legagneux et al. 2009
	Lower Mississippi Alluvial Valley, USA	2005 and 06/T	W	2.5	R/W	Davis and Afton 2010
	Cameron Prairie NWR, Louisiana, USA	2004-05/T	W	4.6	R/W/T	Link et al. 2011
	Cameron Prairie NWR, Louisiana, USA	2005-06/T	W	3.4	R/W/T	Link et al. 2011
	Lacassine NWR, Louisiana, USA	2004-05/T	W	4.4	R/W/T	Link et al. 2011
	Lacassine NWR, Louisiana, USA	2005-06/T	W	15.0	R/W/T	Link et al. 2011
	SW Louisiana, USA	2004-05/T	W	3.1	R/W/T	Link et al. 2011
	SW Louisiana, USA	2005-06/T	W	4.3	R/W/T	Link et al. 2011
	SW (White L. WCA) Louisiana, USA	2004-06/T	W	11.3	R/W/T	Link et al. 2011
	Texas High Plains, USA	1980-82/U	W	5.0	T	Baldassarre and Bolen 1984
	Platte River Valley, Nebraska, USA	1980/T	W	3.2	T	Jorde et al. 1983
	California Central Valley (N), USA	1988-90/T	W	4.8	R/W/T	Fleskes et al. 2005
	California Central Valley (N), USA	1998-00/T	W	3.6	R/W/T	Fleskes et al. 2005
American Black Duck	Chincoteague NWR, Virginia, USA	1985-86/T	W	2.8	W	Morton et al. 1989

(con'd)

Northern Pintail	W. (Moëze) France	2004-05/T	W	1.3	W	Legagneux et al. 2009
	Texas High Plains, USA	1980-82/U	W	5.0	T	Baldassarre and Bolen 1984
	Texas High Plains, USA	2002-03/T	W	11.0	T/W	Moon 2004
	Texas High Plains, USA	2003-04/T	W	7.0	T/W	Moon 2004
	Texas coast, USA	2002-03/T	W	3.8	R/W	Anderson 2008
	Texas coast, USA	2003-04/T	W	2.6	R/W	Anderson 2008
	SW Louisiana, USA	1991-92/T	W	10.7 <sup>  </sup>	R/W/T	Cox and Afton 1996
	SW Louisiana, USA	1991-92/T	W	18.5 <sup>  </sup>	R/W/T	Cox and Afton 1996
	SW Louisiana, USA	1992-93/T	W	18.3 <sup>  </sup>	R/W/T	Cox and Afton 1996
	SW Louisiana, USA	1992-93/T	W	14.5 <sup>  </sup>	R/W/T	Cox and Afton 1996
	Rainwater Basin, Nebraska, USA	2001, 03-04/ T	S	4.3	T/W	Pearse et al. 2011
	California Central Valley (N), USA	1991-94/T	W	5.6	R/W/T	Fleskes et al. 2005
	California Central Valley (N), USA	1998-00/T	W	7.0	R/W/T	Fleskes et al. 2005
	California Central Valley (C), USA	1991-94/T	W	3.3	R/W/T	Fleskes et al. 2005
	California Central Valley (C), USA	1998-00/T	W	4.7	R/W/T	Fleskes et al. 2005
	California Central Valley (S), USA	1991-94/T	W	4.0	R/W/T	Fleskes et al. 2005
California Central Valley (S), USA	1998-00/T	W	4.5	R/W/T	Fleskes et al. 2005	
American Wigeon	Texas High Plains, USA	1980-82/U	W	5.0	T	Baldassarre and Bolen 1984
Eurasian Wigeon	W. (Saint-Denis-du-Payré) France	2003-04/T	W	2.8		H. Fritz, <i>personal communication</i>
	Camargue, France	1926-04/R	W	2.5, (2-3) <sup>¶¶</sup>	W	Guillemain et al. 2008
Gadwall	Camargue, France	1926-04/R	W	2.5, (2-3) <sup>¶¶</sup>	W	Guillemain et al. 2008
	Camargue, France	1926-04/R	W	2.5, (2-3) <sup>¶¶</sup>	W	Guillemain et al. 2008
Northern Shoveler Teal	N. (Seine) France	2002-03/T	W	3.8	W	Legagneux et al. 2009
	N. (Seine) France	2003-04/T	W	2.3	W	Legagneux et al. 2009
	C. (Brenne) France	2002-03/T	W	0.8	W	Legagneux et al. 2009
	C. (Brenne) France	2003-04/T	W	8.4	W	Legagneux et al. 2009
	W. (Moëze) France	2004-05/T	W	1.0	W	Legagneux et al. 2009
	Camargue, France	1926-04/R	W	2.5, (2-3) <sup>¶¶</sup>	W	Guillemain et al. 2008
	Texas High Plains, USA	1980-82/U	W	5.0	T	Baldassarre and Bolen 1984
	Green-winged Teal	Texas High Plains, USA	1980-82/U	W	5.0	T

<sup>†</sup> C = Central; L = Loch(s) or Lake, N = North/Northern; NE = Northeast, NNR = National Nature Reserve; NWR = National Wildlife Refuge, S = South/Southern; SW = Southwest, W = Western; WCA = Wetland Conservation Area.

<sup>‡</sup> U = unmarked; T = telemetry; C = color marked (neck bands), R = marked with leg ring/band.

<sup>§</sup> W = winter, S = spring.

<sup>||</sup> Study addressed percent of total feeding time (number of geese observed in fields multiplied by time spent feeding) that took place within given distances from the roost. The value is first incremental distance that accounted for over 50% of total feeding time.

<sup>¶</sup> Median distance. For Patterson et al. (1989), value is based on average of 6 median values from their Table 6.

<sup>#</sup> Distance at which grazing intensity ([number observed/number observation days]/field size) became consistently rare because of limited use.

<sup>††</sup> Average from Figure 10 (in Hobbs 1999) using values provided in text for periods 1 and 4, and interpolated from y-axis for periods 2 and 3.

<sup>‡‡</sup> Geese typically made morning, midday, and afternoon field feeding flights; value represents average of longest periods in each year.

<sup>§§</sup> Average feeding distance was presented by feeding area and year with no statistical test; 7.5 km is longest distance.

<sup>||</sup> Average calculated from Table 1 for the period 30 October - 22 February; their equation was based on 198 flights of 108 females.

<sup>¶¶</sup> Median distance that banded ducks radiated from roost sites.

<sup>###</sup> General habitat types, as indicated by authors, that were the destination of foraging flights: T = terrestrial; W = wetlands; and, R = rice.

Seasonal differences were considered in the analysis or presentation of 41 of the 69 FFD values, excluding unpublished data (Table 2). Seasonal differences were evident in 34 of those 41 cases, and it was found in 16 of these cases that waterfowl fed farther from the roost site as the season progressed. In 8 of the 34 cases, waterfowl fed closer to the roost as the season progressed. For the remaining cases, FFD varied among weeks, months, or winter periods with no consistent trend, or varied between hunting and nonhunting periods. One study found seasonal differences in FFD with respect to habitat use; Davis and Afton (2010) observed that Mallards (*Anas platyrhynchos*) foraging in wetlands fed closer to the roost as the season progressed, whereas those foraging in rice fields fed further from the roost.

We evaluated eight a priori models, including an intercept-only model, and found that one model, Guild + Location, provided

the best approximation of the available data (Table 3). This model had an Akaike weight ( $w_i$ ; Burnham and Anderson 2002) of 0.7, indicating there was a 70% chance that it was the best model of the set. For our top model, we found a positive effect of Guild ( $\beta = 3.9$ , SE = 1.3) and Location ( $\beta = 4.2$ , SE = 1.3) on FFD.

The average FFD for geese was  $7.8 \pm 7.2$  km (mean  $\pm$  SD,  $n = 24$ ) and was longer than the average of  $5.1 \pm 4.4$  km ( $n = 46$ ) reported for dabbling ducks. The average FFD for waterfowl in the Nearctic was  $7.4 \pm 6.7$  km (mean  $\pm$  SD,  $n = 39$ ) and longer than the average of  $4.2 \pm 3.2$  km ( $n = 31$ ) reported for Palearctic waterfowl. Spring FFD values were not included in the model, but six of the seven spring values were for geese and they averaged  $9.0 \pm 7.8$  km.

Major study purpose(s) associated with FFD values ( $n = 69$ ), excluding unpublished data, included assessing foraging

**Table 2.** Studies supporting temporal effects, either through statistical evaluation or qualitative presentation of data, in distance waterfowl fly from roost sites to forage. Scientific names for all species listed in Appendix 1.

Species (subspecies)	Source (general location <sup>†</sup> )	Year(s)	Seasonal evidence <sup>§</sup>	Increase (+) or decrease (-) in distance time/season
Greylag Goose	Patterson et al. 1989	1984-86	Y <sup>‡</sup>	Inconsistent <sup>¶</sup>
	Bell 1988	1983-86	Y	- winter period
Pink-footed Goose	Patterson et al. 1989	1984-86	Y <sup>‡</sup>	Inconsistent <sup>¶</sup>
	Giroux and Patterson 1995	1987-88	N	
	Bell 1988	1983-86	N	
Bean Goose	Nilsson and Persson 1984	1977-88	Y <sup>‡</sup>	Inconsistent <sup>¶</sup>
Greater White-fronted Goose (tule)	Ackerman et al. 2006	1987-90	Y	Inconsistent <sup>¶</sup>
	Ackerman et al. 2006	1998-00	Y	- month
Snow Goose (greater) Canada Goose	Hobbs 1999	1995-96	Y	+ winter period
	Hill and Frederick 1997	1990-91	Y	Inconsistent <sup>¶</sup>
(dusky) Cackling Goose	Austin 1988	1985-87	Y	+ winter period
	Harvey et al. 1998	1984-86	Y	+ date
Mallard	Mini 2012	2007-09	Y	Inconsistent <sup>¶</sup>
	Mini 2012	2007-09	Y	Inconsistent <sup>¶,¶</sup>
	Legagneux et al. 2009 (Seine)	2002-03	Y	- date
	Legagneux et al. 2009 (Seine)	2003-04	Y	- date
	Legagneux et al. 2009 (Brenne)	2001-02	Y	- date
	Legagneux et al. 2009 (Brenne)	2002-03	Y	- date
	Legagneux et al. 2009 (Brenne)	2003-04	Y	- date
	Davis and Afton 2010	2005-06	Y	+,- <sup>††</sup>
	Link et al. 2011(Cameron Prairie NWR)	2004-05	N	
	Link et al. 2011 (Cameron Prairie NWR)	2005-06	N	
	Link et al. 2011 (Lacassine NWR)	2004-05	Y	+ date
	Link et al. 2011 (Lacassine NWR)	2005-06	Y	+ date
	Link et al. 2011 (southwest Louisiana)	2004-05	N	
	Link et al. 2011 (southwest Louisiana)	2005-06	N	
Northern Pintail	Jorde et al. 1983, 1984	1980	N <sup>‡</sup>	
	Legagneux et al. 2009	2004-05	Y	+ date
	Moon 2004	2002-03	Y	Inconsistent <sup>¶,¶</sup>
	Moon 2004	2003-04	Y	Inconsistent <sup>¶,¶</sup>
	Anderson 2008	2002-03	Y <sup>‡</sup>	Inconsistent <sup>¶</sup>
	Anderson 2008	2002-03	Y <sup>‡</sup>	Inconsistent <sup>¶</sup>
	Cox and Afton 1996 (adult <sup>‡</sup> )	1991-92	Y	+ date
	Cox and Afton 1996 (first winter <sup>‡</sup> )	1991-92	Y	+ date
	Cox and Afton 1996 (adult <sup>‡</sup> )	1992-93	Y	+ date
	Cox and Afton 1996 (first winter <sup>‡</sup> )	1992-93	Y	+ date
Teal	Legagneux et al. 2009 (Seine)	2002-03	Y	+ date
	Legagneux et al. 2009 (Seine)	2003-04	Y	+ date
	Legagneux et al. 2009 (Brenne)	2002-03	Y	+ date
	Legagneux et al. 2009 (Brenne)	2003-04	Y	+ date
	Legagneux et al. 2009 (Moëze)	2004-05	Y	+ date

<sup>†</sup> General location is only given for studies that report values from multiple locations; NWR = National Wildlife Refuge.

<sup>‡</sup> Cox and Afton (1996) found differences between first winter and adult birds.

<sup>§</sup> Y = Yes (“evidence” was found); N = No (“evidence” was not found).

<sup>‡</sup> No statistical test for temporal effects of date, week, month, or winter period was performed, but data were presented in a way that it could be interpreted qualitatively.

<sup>¶</sup> Inconsistent = temporal differences (e.g., week-to-week or month-to-month differences) supported, but no overall positive or negative trend across periods.

<sup>#</sup> Hunting season effect (e.g., prehunt, hunt, posthunt).

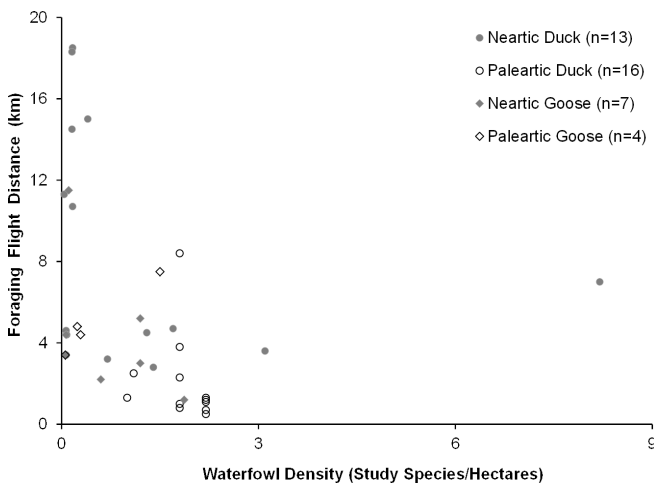
<sup>††</sup> Foraging flight distance (FFD) of Mallards foraging on rice increased with date while FFD of Mallards foraging on natural foods decreased with date.

**Table 3.** A priori models relating mean foraging flight distances (Mean FFD [km]) to explanatory variables: body mass (Mass [g]), guild (goose or duck), and location (Nearctic and Palearctic). For each model, we displayed the number of parameters (K), Akaike's Information Criterion corrected for small sample sizes ( $AIC_c$ ), and the change in  $AIC_c$  from the smallest  $AIC_c$  value ( $\Delta AIC_c$ ), and Model Weight ( $w_i$ ).

Model	K	$AIC_c$	$\Delta AIC_c$	$w_i$
Guild + Location	3	433.5	0.0	0.7
Guild*Location	4	435.7	2.2	0.2
Mass*Location	4	439.1	5.6	0.0
Location	2	439.4	6.0	0.0
Mass + Location	3	440.2	6.7	0.0
Guild	2	441.4	8.0	0.0
1	1	443.2	9.7	0.0
Mass	2	444.6	11.2	0.0

movements in 55% of cases; assessing use of or preference for habitat in 52% of cases; assessing spatial use and/or home range in 20% of cases; addressing crop depredation issues in 13% of cases, describing foraging ecology in 12% of cases; and describing distribution in 12% of cases (Table 4). Studies addressing crop depredation were limited to the Palearctic. We were able to obtain the density of studied species for 54% of the 70 winter FFD values (Table 4). A qualitative assessment suggests FFD does not increase as bird densities get larger (Fig. 2).

**Fig. 2.** Relationship between foraging flight distance (FFD) and density (study species/hectare) for waterfowl in the Nearctic and Palearctic.



## DISCUSSION

Our review suggests that dabbling ducks and geese potentially forage in a substantial zone (Table 1) around their winter roost sites. Even so, estimates from this review are conservative; values used in our analysis represented mean and median FFDs of wild birds in habitats of varying quality and resource juxtaposition. The analysis was not based on values representing the upper FFD distance, because feeding on or near maximum FFD is likely not energetically sustainable. Flight is the most energetically demanding behavior of wintering birds (King 1974, Austin and

Humburg 1992, Owen et al. 1992, McKinney and McWilliams 2005), and the balance between daily intake of metabolizable energy and energy expenditure would likely be compromised by a sustained pattern of prolonged foraging flights (Pearse et al. 2010, Baveco et al. 2011). Short-duration flights have higher costs per time unit than long flights because of the high energetic costs of takeoff and climbing (Gauthier et al. 1984, Nudds and Bryant 2000), but total energy expenditure should increase as FFD increases. Moreover, waterfowl are likely to spend less time foraging at sites farther from roosts, because giving-up density for food resources increases with FFD (van Gils and Tijssen 2007). Thus, conservation actions occurring within the average FFD are less likely to be compromised because of the energetic cost of long flights.

Foraging types associated with FFD values were highly skewed by guild and location (Fig. 1). Goose FFD values were mainly associated with terrestrial habitats, and those of Palearctic dabbling ducks were solely associated with wetlands. Interestingly, the longest average FFDs for both geese and dabbling ducks were from studies documenting rice as a foraging flight destination (Cox and Afton 1996, Fleskes et al. 2005, Link et al. 2011). The energy available in rice fields from rice and nonrice seeds, vegetative parts of plants, and invertebrates (Manley et al. 2004) may allow waterfowl to make long foraging flights and maintain their energy balance. It is interesting that FFD values in the Palearctic were all associated with a single habitat type, whereas FFD values in the Nearctic were commonly associated with multiple habitat types (Fig. 1). These differences may be associated with the questions addressed in Palearctic and Nearctic studies (Table 4). For example, a study focused on crop depredation may not be designed to capture foraging flights made to wetlands habitats.

Refuging theory (Hamilton and Watt 1970) suggests that waterfowl will deplete food resources near roost areas first and radiate farther from roost sites to forage as the season progresses (Frederick et al. 1987, Cox and Afton 1996, Gill 1996); however, studies of dabbling ducks and geese have provided mixed support for this theory (Table 2). Predicted effects of refuging theory could be negated or masked because the types of foods available are temporally staggered in availability (Frederick and Klaas 1982, Moon 2004); because some depleted foods, e.g., grasses, regrow (Bos et al. 2004, Van Der Graaf et al. 2005); because birds switch

**Table 4.** Study purpose and density (birds/ha; when available) associated with foraging flight distance (FFD) values used to evaluate the influence of guild, mass, and location on distances flown by waterfowl between roost and foraging areas. Scientific names for all species listed in Appendix 1.

Species (subspecies)	General location <sup>†</sup>	Major study purpose(s)	Bird/ha <sup>‡</sup>	Source
Greylag Goose	NE Scotland	Crop damage	0.06	Patterson et al. 1989
	NE (L. Strathbeg) Scotland	Habitat preference; crop damage		Bell 1988
	NE (Slains L.) Scotland	Habitat preference; crop damage		Bell 1988
	NE (Skene L.) Scotland	Habitat preference; crop damage		Bell 1988
Pink-Footed Goose	NE (Dinnet L.) Scotland	Habitat preference; crop damage		Bell 1988
	NE Scotland	Crop damage	0.29	Patterson et al. 1989
	Holkham NNR, Norfolk, England	Habitat preferences; habitat management conflicts		Vickery et al. 1997
Bean Goose	NE Scotland	Crop damage	0.24	Giroux and Patterson 1995
	NE (L. Strathbeg) Scotland	Habitat preference; crop damage		Bell 1988
	NE (Slains L.) Scotland	Habitat preference; crop damage		Bell 1988
Greater White-fronted Goose	SW Skåne, Sweden	Habitat use		Nilsson & Persson 1984
(tule)	California Central Valley, USA	Spatial use		Ackerman et al. 2006
	California Central Valley, USA	Spatial use		Ackerman et al. 2006
	L. Izunuma-Uchinuma, Japan	Habitat use		Shimada 2003
(Greenland)	Delevan NWR, California, USA	Habitat use	0.07 <sup>§</sup>	Hobbs 1999
Snow Goose (greater)	Holkham NNR, Norfolk, England	Habitat preferences; habitat management conflicts		Vickery et al. 1997
	Delmarva Peninsula, USA	Habitat use; foraging flights		Hill and Frederick 1997
Snow Goose (lesser)	C. Missouri River Valley, USA	Bird behavior; habitat use	< 0.11	Davis et al. 1989
Dark-bellied Brent	Holkham NNR, Norfolk, England	Habitat preferences; habitat management conflicts		Vickery et al. 1997
Canada Goose	Missouri, USA	Habitat use; foraging ecology	0.6	Austin 1988
	Maryland, USA	Habitat use; foraging flights	1.87	Harvey et al. 1998
(dusky)	Willamette Valley, Oregon, USA	Habitat preference; foraging ecology	< 1.2	Mini 2012
Cackling Goose	Willamette Valley, Oregon, USA	Habitat preference; foraging ecology	< 1.2	Mini 2012
Barnacle Goose Mallard	Solway Firth, Great Britain	Habitat use in response to refugia	< 1.5	Owen et al. 1987
	N. (Seine) France	Home range; foraging flights	2.2	Legagneux et al. 2009
	N. (Seine) France	Home range; foraging flights	2.2	Legagneux et al. 2009
	C. (Brenne) France	Home range; foraging flights	2.2	Legagneux et al. 2009
	C. (Brenne) France	Home range; foraging flights	2.2	Legagneux et al. 2009
	C. (Brenne) France	Home range; foraging flights	2.2	Legagneux et al. 2009
	Lower Mississippi Alluvial Valley, USA	Home range; foraging flights	2.2	Legagneux et al. 2009
	Lower Mississippi Alluvial Valley, USA	Home range; foraging flights	2.2	Davis and Afton 2010
	Cameron Prairie NWR, Louisiana, USA	Foraging flights with respect to hunting and habitat	0.07 <sup>l</sup>	Link et al. 2011
	Cameron Prairie NWR, Louisiana, USA	Foraging flights with respect to hunting and habitat	0.07 <sup>l</sup>	Link et al. 2011
	Lacassine NWR, Louisiana, USA	Foraging flights with respect to hunting and habitat	0.08 <sup>§</sup>	Link et al. 2011
Lacassine NWR, Louisiana, USA	Foraging flights with respect to hunting and habitat	0.40 <sup>§</sup>	Link et al. 2011	
SW Louisiana, USA	Foraging flights with respect to hunting and habitat		Link et al. 2011	
SW Louisiana, USA	Foraging flights with respect to hunting and habitat		Link et al. 2011	

(con'd)



	SW (White L. WCA) Louisiana, USA	Foraging flights with respect to hunting and habitat	0.04 <sup>#</sup>	Link et al. 2011
	Texas High Plains, USA	Habitat use; foraging ecology		Baldassarre and Bolen 1984
	Platte River Valley, Nebraska, USA	Foraging ecology	0.7 <sup>††</sup>	Jorde et al. 1983
	California Central Valley (N), USA	Distribution; foraging flights; habitat use		Fleskes et al. 2005
	California Central Valley (N), USA	Distribution; foraging flights; habitat use	3.1	Fleskes et al. 2005
American Black Duck	Chincoteague NWR, Virginia, USA	Habitat use; foraging flights	1.4	Morton et al. 1989
Northern Pintail	W. (Moëze) France	Home range; foraging flights	1.0	Legagneux et al. 2009
	Texas High Plains, USA	Habitat use; foraging ecology		Baldassarre and Bolen 1984
	Texas High Plains, USA	Survival; habitat use; foraging flights		Moon 2004
	Texas High Plains, USA	Survival; habitat use; foraging flights		Moon 2004
	Texas coast, USA	Survival; habitat use; foraging flights		Anderson 2008
	Texas coast, USA	Survival; habitat use; foraging flights		Anderson 2008
	Lacassine NWR, Louisiana, USA	Foraging flights	0.17 <sup>‡</sup>	Cox and Afton 1996
	Lacassine NWR, Louisiana, USA	Foraging flights	0.17 <sup>‡</sup>	Cox and Afton 1996
	Lacassine NWR, Louisiana, USA	Foraging flights	0.16 <sup>‡</sup>	Cox and Afton 1996
	Lacassine NWR, Louisiana, USA	Foraging flights	0.16 <sup>‡</sup>	Cox and Afton 1996
	California Central Valley (N), USA	Distribution; foraging flights; habitat use		Fleskes et al. 2005
	California Central Valley (N), USA	Distribution; foraging flights; habitat use	> 8.2	Fleskes et al. 2005
	California Central Valley (C), USA	Distribution; foraging flights; habitat use		Fleskes et al. 2005
	California Central Valley (C), USA	Distribution; foraging flights; habitat use	> 1.7	Fleskes et al. 2005
	California Central Valley (S), USA	Distribution; foraging flights; habitat use		Fleskes et al. 2005
	California Central Valley (S), USA	Distribution; foraging flights; habitat use	> 1.3	Fleskes et al. 2005
American Wigeon	Texas High Plains, USA	Habitat use; foraging ecology		Baldassarre and Bolen 1984
Eurasian Wigeon	W. (Saint-Denis-du-Payré) France		1.1 <sup>††</sup>	H. Fritz, <i>personal communication</i>
Gadwall	Camargue, France	Harvest dynamics		Guillemain et al. 2008
Northern Shoveler	Camargue, France	Harvest dynamics		Guillemain et al. 2008
Teal	Camargue, France	Harvest dynamics		Guillemain et al. 2008
	N. (Seine) France	Home range; foraging flights	1.8	Legagneux et al. 2009
	N. (Seine) France	Home range; foraging flights	1.8	Legagneux et al. 2009
	C. (Brenne) France	Home range; foraging flights	1.8	Legagneux et al. 2009
	C. (Brenne) France	Home range; foraging flights	1.8	Legagneux et al. 2009
	W. (Moëze) France	Home range; foraging flights	1.8 <sup>††</sup>	Legagneux et al. 2009
	Camargue, France	Harvest dynamics		Guillemain et al. 2008
Green-winged Teal	Texas High Plains, USA	Habitat use; foraging ecology		Baldassarre and Bolen 1984

<sup>†</sup> C = Central; L = Loch(s) or Lake, N = North/Northern; NE = Northeast, NNR = National Nature Reserve; NWR = National Wildlife Refuge, S = South/Southern; SW = Southwest, W = Western; WCA = Wetland Conservation Area.

<sup>‡</sup> Density value is from the source study unless otherwise indicated.

<sup>§</sup> Area (ha) from Fleskes et al. (2005)

<sup>||</sup> Louisiana Department of Wildlife and Fisheries (LDWF) waterfowl surveys: <http://www.wlf.louisiana.gov/hunting/aerial-waterfowl-surveys> accessed 16 July 2014, and U.S. Fish and Wildlife Service (2006); Mallard and Pintail numbers were calculated by multiplying the percent of each species observed in duck surveys in southwest Louisiana to the total number of ducks reported on refuge surveys (U.S. Fish and Wildlife Service 2006); area (ha) from U.S. Fish and Wildlife Service (2006).

<sup>¶</sup> All information from U.S. Fish and Wildlife Service (2007).

<sup>#</sup> Abundance at Amoco Pool (White Lake Preserve, Inc.) is from LDWF waterfowl surveys: <http://www.wlf.louisiana.gov/hunting/aerial-waterfowl-surveys> accessed 16 July 2014; area (ha) is that of Amoco Pool.

<sup>††</sup> Legagneux et al. (2009)

to different types of forage because of annual cycle requirements (Vickery and Gill 1999); or because of hunting and other disturbances (Moon 2004, Fleskes et al. 2005, Mini 2012).

The average FFD of dabbling ducks was closer to roost sites than the average FFD of geese, irrespective of location. Morphological and behavioral difference in geese may allow them to maintain their energy balance while foraging further away from roosts sites. The esophagus or foregut of waterfowl is distensible, allowing for temporary food storage (Drobney 1984, Gill 1990). Mallards returning to roost sites after field feeding often have an esophagus that is distended with corn (Whyte and Bolen 1985), and although geese lack a crop, their esophagus may also swell with food before returning to the roost (Owen 1972). Moreover, consumption of food by geese often exceeds the rate at which it can be processed in the hindgut, indicating short-term storage in the esophagus until it can proceed through the digestive system (Bédard and Gauthier 1989). Although structurally different, the esophagus of geese is proportionally longer than that of dabbling ducks, so geese undergoing long foraging flights may be able to maintain their energy balance because they can return to the roost carrying substantial amounts of food (estimate of 100 ml in White-fronted Geese; Owen 1972). Additionally, geese spend longer amounts of time at the destination of their foraging flights, e.g., pastures, and longer amounts of time foraging in these sites (Davis et al. 1989, Owen et al. 1992, Mini and Black 2009) than dabbling ducks (Winner 1959, Jorde et al. 1983). Moreover, geese often rest/loaf while in fields (Austin 1988, Davis et al. 1989, Ely 1992), and these bouts of resting/loafing may allow for food temporarily stored in the esophagus to pass into the hindgut before foraging continues (Bédard and Gauthier 1989, Fox et al. 2008a). Because of the larger size of geese, the frequency of predator-related disturbances and associated energy expenditure, e.g., flushing, short flights, may be lower for geese than for dabbling ducks, because smaller waterfowl are disturbed more frequently by aerial predators and by a larger suite of raptor species (McWilliams et al. 1994, Johnson and Rohwer 1996). Thus, the energetic costs of longer foraging flights in geese may be offset because they spend more time in fields, forage longer, rest in fields to allow time for food passage, have proportionately longer esophagi, and may perceive fewer predation risks.

Although the energetic cost of straight-line flight suggests larger animals within taxa, e.g., larger bees, larger waterfowl, are more efficient fliers and subsequently might fly farther (Schmidt-Nielsen 1972, Greenleaf et al. 2007, Mini 2012), the variety of landscapes and diversity in value/quality of energetic resources in the reviewed studies may have been a reason we did not find an effect of body mass. Likewise, strong guild differences, perhaps because of morphology or behavior, may have also influenced our results.

Our review suggests FFDs in the Nearctic are longer than those in the Palearctic, perhaps because of larger concentrations of waterfowl in the Nearctic and, therefore, greater exploitation of food resources near roost areas (Legagneux et al. 2009). That is, Nearctic waterfowl may be more food limited. However, a qualitative appraisal suggests that FFD does not increase with increasing waterfowl densities (Fig. 2). A major issue with trying to relate bird concentrations to FFD is that density information is generally specific to a brief point in time such as early January,

whereas FFD information is typically collected over the duration of the study. Density information would have more value in the interpretation of FFD if it were collected over an appropriate time frame. FFD may also be related to differences between locations, including hunting pressure, the habitat types that were used, the nutritional quality and quantity of food resources, or landscape characteristics such as the proximity of foraging areas and roost areas (Legagneux et al. 2009). Terrestrial foraging habitats described in Nearctic studies commonly consisted of corn, perennial grasses, rice, small grains/cereals, sorghum, soybeans, and winter wheat; whereas those in Palearctic studies commonly consisted of perennial grasses, potatoes, small grains/cereals, sugar beets, winter wheat, and barley. FFDs of Snow Geese utilizing small grains, soybeans, and corn on the Delmarva Peninsula, Delaware, USA, were greater than distances associated with salt marsh, freshwater impoundments, sorghum, perennial grasses, and other habitat types (Hill and Frederick 1997). Nilsson and Persson (1984) noted that Taiga Bean Geese (*Anser fabalis fabalis*) wintering in southwest Skåne, Sweden, tended to make longer foraging flights when traveling to sugar beet fields than when foraging in other habitats. High-energy foods, which one might associate with longer foraging flights, were available in both the Nearctic and Palearctic, so perhaps the quantity of waste grain available after harvest or some other agricultural practice might be influencing differences in FFD between the two locations. Most studies described the general types of terrestrial and other foraging habitats available, but rarely did they report habitat-specific FFDs unless they were dealing with one type of foraging habitat. Thus, we could not address the effect that foraging habitat had on FFD. FFD values for Palearctic dabbling ducks were solely associated with wetland feeding. Therefore, functional units utilized by wintering dabbling ducks in the Palearctic might differ from those in the Nearctic, in that Palearctic sites frequently consist of wetland complexes that contain both roost sites and foraging sites in close proximity (M. Guillemain, *personal communication*). Likewise, terrestrial foraging geese in the Palearctic might encounter a greater diversity of agricultural crops and foraging options near their roosts sites because of drastically smaller farm sizes in this region. More than 50% of farms in the European Union are less than 4.9 hectares in size and only 8% of European Union farms exceed 57 hectares, whereas approximately one-half of United States farms are larger than 57 hectares in size and more than 20% exceed 202 hectares (Normile and Price 2004). Although our review suggests that waterfowl in the Palearctic forage closer to roost sites, it should be noted that long-distance foraging flights do occur in the Palearctic, because regular nocturnal flights in excess of 40 km were suspected for Middendorff's Bean Geese (*Anser fabalis middendorffii*) wintering in China (Fox et al. 2008b); however, the authors were unable to regularly follow the birds because of terrain.

## CONCLUSIONS

Our results could be used to (1) refine energetic carrying capacity estimates around roost sites for wintering waterfowl; (2) inform planning for wetland complexes, including additional roost wetlands, in agricultural or natural landscapes with local energetic carrying capacity in mind; (3) inform management actions aimed at alleviating crop depredation; and (4) inform management decisions concerning actions that are intended to alter energetic

resources at both the local and landscape levels. For instance, if cropland food resources are underutilized or unavailable because of distance from roost sites, programs that lease and flood agricultural fields to provide waterfowl with secure roost sites and access to food resources could be considered (Riley et al. 2005). Similarly, assumptions about FFD of waterfowl from roost sites on conservation lands, e.g., refuges, could be factored into ranking criteria and funding of wetland programs, e.g., wetland restoration programs administered by U.S. Department of Agriculture. Understanding FFD is paramount to managing crop depredation programs such as alternative feeding areas or lure crops, because severity of waterfowl damage to agricultural crops is inversely related to distance from roost wetlands (Sugden 1976, Arsenault 1994, Amano et al. 2007). Consideration of FFD has also been suggested in planning for and managing waterfowl reserves in Europe (Mooij 1992) and wetland complexes along migratory routes in North America (Pearse et al. 2011). Although we report average FFD values by guild and by location, reviewed data (Table 1) could be used to calculate FFD that was specific to a focal species, group, or location. Although FFD may be useful in calculating daily energy budgets of migrating and wintering waterfowl, the distance flown from roosts to feeding areas may underestimate daily flight expenditures if birds are repeatedly disturbed or if they make repeated short flights to access secondary feeding areas as part of a single foraging trip (Mooij 1992, Clausen et al. 2013).

Information concerning FFD also could be incorporated into decision support tools used in landscape planning, including tools that inform placement of tall infrastructure. Wintering and migrating waterfowl departing roost sites tend to fly at low altitudes (Williams et al. 1976, Randall et al. 2011), and depending on species and locality, foraging flights may occur one or more times per day and may take place under a variety of light and weather conditions (Raveling et al. 1972, Jorde et al. 1984, Austin and Humburg 1992, Cox and Afton 1996, Randall et al. 2011). Wind turbines, transmission lines, and other tall infrastructure placed within the foraging zone around roost sites may put waterfowl at risk of collision hazards or alter the energetic carrying capacity of the landscape because of displacement from feeding sites (Larsen and Madsen 2000, Drewitt and Langston 2006, Kuvlesky et al. 2007, Rees 2012). Unfortunately, FFD information in the reviewed studies was not sufficient to address the impacts of tall infrastructure. Rees (2012) noted that insufficient attention has been paid to the potential for wind turbines to displace waterfowl from feeding sites used during the nonbreeding season. We concur, and call for additional studies evaluating the impacts of tall infrastructure placed near traditional roost sites.

Responses to this article can be read online at:  
<http://www.ace-eco.org/issues/responses.php/683>

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#### Acknowledgments:

We thank H. Fritz for allowing us to use unpublished data. Matthew Butler, Dan Collins, and Barry Wilson provided helpful feedback on early drafts of this manuscript. Matthew Butler and Sarah

Lehmen also provided statistical advice and recommendations. Tommy Michot graciously provided a translation of the article by Tamisier and Tamisier (1981). The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

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#### LITERATURE CITED

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**Appendix 1.** Waterfowl mass values that were used in analysis of foraging flight distances. Citations included in the literature cited of the main text are not repeated in the literature cited that follows this table.

Common Name	Species	Group	Location	Mass (g) <sup>a</sup>	Source <sup>f</sup>
Greylag Goose	<i>Anser anser</i>	goose	Paleartic	3360.0	Robinson 2005
Pink-footed Goose	<i>A.brachyrhynchus</i>	goose	Paleartic	2450.0	Robinson 2005
Bean Goose	<i>A. f. fabalis</i>	goose	Paleartic	2984.0	Szczepańczyk et al. 2000
Greater White-fronted Goose	<i>A. a. albifrons</i> <sup>q</sup>	goose	Paleartic	2340.0 <sup>b</sup>	Takekawa et al. 2000
	<i>A. a. elgasi</i> <sup>q</sup>		Nearctic	2848.6 <sup>c</sup>	Ely and Dzubin 1994
	<i>A. a. gambelli</i> <sup>q</sup>		Nearctic	2115.5 <sup>d</sup>	Ely and Dzubin 1994
	<i>A. a. flavirostris</i> <sup>q</sup>		Paleartic	2594.0 <sup>e</sup>	Fox and Stroud 2002
Snow Goose (greater)	<i>Chen caerulescens atlantica</i>	goose	Nearctic	2651.5	Mowbray et al. 2000
Snow Goose (lesser)	<i>C. c. caerulescens</i>		Nearctic	2069.8	Flickinger and Bolen 1979
Dark-bellied Brent	<i>Branta b. bernicla</i>	goose	Paleartic	1421.0	Stahl et al. 2002
Canada Goose	<i>B. canadensis interior</i>	goose	Nearctic	4330.0	Moser and Rolley 1990
Canada Goose (dusky)	<i>B. c. occidentalis</i>		Nearctic	3411.8	Chapman 1970, Bromley and Jarvis 1992
Cackling Goose	<i>B. hutchinsii minima</i>	goose	Nearctic	1475.0	Raveling 1979
Cackling Goose (Aleutian)	<i>B. h. leucopareia</i>		Nearctic	1824.8	Mowbray et al. 2002
Barnacle Goose	<i>B. leucopsis</i>	goose	Paleartic	1850.0	Robinson 2005
Mallard	<i>Anas platyrhynchos</i>	dabbling duck	Nearctic	1204.4 <sup>f</sup>	Rhodes et al. 1996
			Nearctic	1172.2 <sup>g,p</sup>	Link 2007
			Nearctic	1152.8 <sup>h,p</sup>	Davis 2007
			Nearctic	1177.8 <sup>i</sup>	Miller et al. 2009
			Paleartic	1110.8	Owen and Cook 1977

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Common Name	Species	Group	Location	Mass (g)	Source
American Black Duck	<i>A. rubripes</i>	dabbling duck	Nearctic	1258.0	Krementz et al. 1989
Northern Pintail	<i>A. acuta</i>	dabbling duck	Nearctic	901.5 <sup>j</sup>	Baldassarre and Bolen 1986
♀			Nearctic	931.0 <sup>k</sup>	Miller et al. 2009
♀			Nearctic	785.9 <sup>l</sup>	Moon 2004
♀ (first winter)			Nearctic	726.2 <sup>m</sup>	Cox et al. 1998
♀ (adult)			Nearctic	771.1 <sup>n</sup>	Cox et al. 1998
♀			Nearctic	783.0 <sup>o</sup>	Anderson 2008
			Paleartic	994.6	Guillemain et al. 2002
American Wigeon	<i>A. americana</i>	dabbling duck	Nearctic	730.6	Rhodes et al. 2006
Eurasian Wigeon	<i>A. penelope</i>	dabbling duck	Paleartic	729.2	Robinson 2005
Gadwall	<i>A. strepera</i>	dabbling duck	Paleartic	817.0	Robinson 2005
Northern Shoveler	<i>A. clypeata</i>	dabbling duck	Paleartic	621.1	Robinson 2005
Teal	<i>A. crecca</i>	dabbling duck	Paleartic	347.6	Guillemain et al. 2002
Green-winged Teal	<i>A. c. carolinensis</i>	dabbling duck	Nearctic	338.0	Baldassarre and Bolen 1986

<sup>a</sup>For analysis, footnoted masses were associated with the following flight distances (see Table 2): <sup>b</sup>Shimada (2003), <sup>c</sup>Hobbs (1999), <sup>d</sup>Ackerman et al. (2006), <sup>e</sup>Vickery et al. (1997), <sup>f</sup>Baldassarre and Bolen (1984), and Jorde et al. (1983), <sup>g</sup>Link et al. (2011), <sup>h</sup>Davis and Afton (2010), <sup>i</sup>Fleskes et al. (2005), <sup>j</sup>Baldassarre and Bolen (1984), <sup>k</sup>Fleskes et al. (2004), <sup>l</sup>Moon (2004), <sup>m,n</sup>Cox and Afton (1996), and <sup>o</sup>Anderson (2008); if not footnoted, masses were associated to species/subspecies as appropriate based on location (Nearctic or Palearctic).

<sup>p</sup> Values are size-adjusted body mass (calculated based on morphometric variables).

<sup>q</sup> Greater White-fronted Goose subspecies follow Banks (2011).

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