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Abstract.—Numbers of Double-crested Cormorants (*Phalacrocorax auritus*) wintering in the southeastern United States have increased dramatically during the last 30 years concomitant with the rise of the aquaculture industry in this region. These cormorants commonly foraged at commercial aquaculture facilities and thereby came into conflict with farmers. Various interest groups are seeking ecologically sound strategies for minimizing the effects of burgeoning cormorant populations. Therefore, this study was conducted to estimate winter and summer home ranges of cormorants captured in the southeastern U.S. and determine whether age class, body mass, density of aquaculture facilities and availability of roost sites influenced size of these home ranges. Mean ± SE home range size and core use area of satellite transmitter-marked cormorants wintering in the southeastern U.S. from 1999 to 2001 were 17,490 ± 1,986 km^2 (N = 37) and 1,550 ± 265 km^2 (N = 37), respectively. Winter home range size was not affected by region, age class or body mass. Summer home range and core use area of marked cormorants was 30,547 ± 6,197 km^2 (N = 6) and 3,124 ± 1,019 km^2 (N = 6), respectively. *Received 28 September 2007, accepted 1 November 2009.*

Key words.—aquaculture, Double-crested Cormorant, home range, movements, *Phalacrocorax auritus,* platform transmitter, PTT, satellite telemetry, summer, winter.

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Numbers of Double-crested Cormorants (*Phalacrocorax auritus*, hereafter cormorants) wintering in the southeastern United States have increased dramatically during the last 30 years concomitant with the rise of the aquaculture industry in this region (Glahn and Stickley 1995; Glahn and King 2004). These cormorants commonly forage at commercial aquaculture facilities and thereby come into conflict with farmers (Glahn *et al.* 1995; King *et al.* 1995; Glahn and King 2004). Glahn *et al.* (2000) estimated that cormorant predation on Channel Catfish (*Ictalurus punctatus*) costs the Mississippi aquaculture industry up to $25 million annually.

In addition to southeastern aquaculture producers, sport and commercial fishermen in the Great Lakes and Northeastern Regions have become concerned about increasing cormorant numbers (VanDeValk *et al.* 2002; Rudstam *et al.* 2004). The various interest groups involved are seeking ecologically sound strategies for mitigating the effects of burgeoning cormorant populations. Previous VHF telemetry studies have provided useful information about local movements and behavior of cormorants wintering in the Alluvial Valley of Mississippi and the Upper Coastal Plain of east-central Mississippi and west-central Alabama (King *et al.* 1995; King 1996; Tobin *et al.* 2002; Dorr *et al.* 2004). However, cormorant home range and core use areas, the effects of age, density of aquaculture facilities, or availability of roost sites on cormorant home ranges have not been studied (Hatch and Weseloh 1999). The Alluvial Valley of Mississippi alone has a much higher density of aquaculture (40,000 ha; USDA 1999), and cormorant night roosts (N = 39) than does the Upper Coastal Plain of east-central Mississippi and west-central Alabama (11,900 ha; USDA 1999; N = 19 roosts; Tobin *et al.* 2002; Dorr *et al.* 2004). Although radio telemetry has provided daily information on transmitter-equipped birds, the logistic constraints involved with the utilization of VHF telemetry preclude its use in effectively addressing larger-scale regional and continental questions concerning cormorant movements.

Satellite transmitters (Platform Transmitter Terminals, PTT) have been used to monitor the movements of many large mammals and some large migratory birds. Recent technology advances have allowed the development of satellite transmitters small enough to be used on cormorants. The use of satellite telemetry will provide much needed information on the local, regional and continental movements of cormorants and will help researchers better evaluate current control methods and develop ecologically sound control strategies.

The objectives of this study were to: 1) estimate winter and summer home ranges and core use areas of cormorants marked near southeastern aquaculture facilities; 2) compare winter home ranges and core use areas of cormorants captured in the Mississippi Alluvial Valley of Arkansas, Louisiana and Mississippi (more numerous ponds and roost sites) vs. those captured in the Upper Coastal Plain of Alabama (fewer ponds and roost sites); and 3) determine if body mass of cormorants affects home range size and core use area.

Methods

Study Site

The study area comprised the Mississippi River Alluvial Valley (MAV) regions of southeastern Arkansas, northeastern Louisiana, and northwestern Mississippi and the Upper Coastal Plain (UCP) of the Tennessee-Tombigbee and Alabama River Valleys in eastern Mississippi and western Alabama (Fig. 1). Cormorants were captured in nine winter night roosts (King *et al.* 1994) near aquaculture-intensive areas from November 1999 through February 2001. Cormorants were fitted with satellite PTTs using a backpack harness (Dunstan 1972; King *et al.* 2000) and released in the capture roost. The gender of captured cormorants was not determined. The age of each captured cormorant was estimated based on plumage. A bird with light-tan chest and neck feathers was classified as immature, and a black bird was classified as an adult (Palmer 1962).

This research was conducted under the following permits: US Department of Agriculture, Wildlife Services, National Wildlife Research Center's Institutional Animal Care and Use Committee Protocol QA-742 and US Department of Interior, US Geological Survey, Federal Bird Banding Permit 20873.

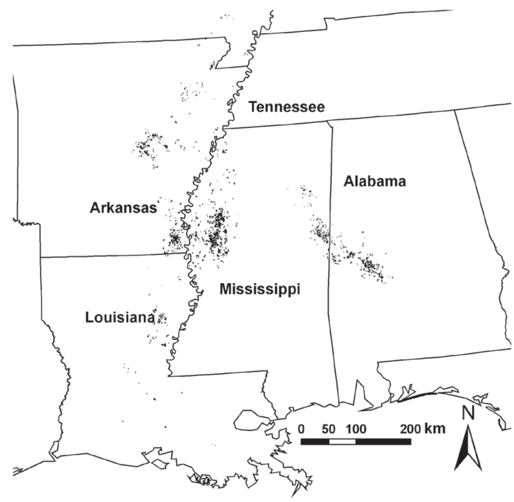

Figure 1. Locations of catfish aquaculture facilities in the Mississippi Alluvial Valley of Arkansas, Mississippi, and Louisiana and the Upper Coastal Plain physiographic regions of Alabama and Mississippi.

PTT Duty Cycles

During the winter of 1999-2000, 45-g PTTs were programmed to transmit for eight hours every 48 h from October through May, and eight hours every ten days from June through September. Microwave Telemetry, Inc. (Columbia, MD) subsequently reduced the weight and increased battery life of their small PTTs. Thus, during the winter of 2000-2001, 30-g PTTs were programmed to transmit for six hours every 48 h from October through mid-June and six hours every ten days from mid-June through September. Using this programming, the expected longevity of the PTTs was twelve months. Service Argos, Inc. (2001) provided data on the locations of the PTTs. Location error was reported by Service Argos, Inc. (2001) as one of six location classes (LC): LC3 = <150 m, LC2 = 150 to <350 m, LC1 = 350 to ≤1000 m, LC0 = >1000 m, LCA and LCB = no estimate of location accuracy.

Statistical Analyses

Douglas' (2000) PC-SAS ARGOS Filter Version 2.4 was used to parse and filter data obtained from Service Argos, Inc. A flight distance of ≤200 km/day and speed of ≤50 km/h were used for two LC filters: 1) a user-defined distance to determine location redundancy, and 2) distance, angle, and rate measurements designed to remove illogical locations. After filtering, location data were plotted and analyzed using ArcGIS 9 (Environmental Systems Research Institute, Inc., Redlands, CA).

Winter (November to February) and summer (June to August) utilization distributions were calculated (Worton 1989) from locations of cormorants during daytime (07.00 to 17.00 h and 07.00 to 18.00 h for winter and summer, respectively) using an adaptive-kernel estimator with the reference bandwidth (h_{ref}). Ninetyfive percent winter and summer home ranges and 50% winter and summer core use areas of PTT-marked cormorants were calculated using the Home Range Extension for ArcGIS® (Rodgers *et al.* 2005) in ESRI® ArcMap™ 9.1 software.

Some researchers favor the fixed-kernel estimator with least squares (see Horne and Garton 2006); however, earlier analyses demonstrated multiple discontinuous use areas using the fixed-kernel estimator with our data (i.e. discontinuous use area derived from one observation peripheral to the center of activity). Thus, based on the distribution patterns observed in our data we elected to use the adaptive-kernel estimator with the reference bandwidth (h_{ref}) to generate more continuous home range areas (Kernohan *et al.* 2001, p. 146).

Although ≥50 samples has been suggested as a minimum for kernel home range estimation by some researchers (Kernohan *et al.* 2001), this sample size would have eliminated >50% of PTT-marked cormorants from the analysis. Instead, cormorants with ≥20 location samples were used for the analysis. The effect of sample size and number of study days on home range size was tested using correlation to determine whether the lesser number of samples (i.e. <50) biased the utilization distribution estimates. Sample size (r = 0.15, P = 0.38) and number of study days (r = 0.24, P = 0.22) were not associated with estimated home range size. Thus, estimates of home range and core use based on ≥20 observations were believed to accurately depict the movement patterns of cormorants in the study areas.

In four cases, distinct shifts were evident in the center of activity of cormorants. The locations of cormorants outside of their center of activity were not included to ensure that home range and core use areas were not artificially increased. Thus, for three cormorants, only observations (N ≥20) surrounding their center of activity were included. One cormorant had >20 observations for both centers of activity, so two home range and core areas were calculated for that individual.

Home range of cormorants in the MAV region was hypothesized to be smaller due to the greater number of aquaculture facilities, thus providing more foraging areas closer to day and evening roost sites (King *et al.* 1995; King 1996). Further, age class (adult vs. immature) was hypothesized to possibly influence home range size. Older cormorants were predicted to occupy the best foraging areas (smaller home ranges) and relegate younger, subordinate cormorants to lower-quality foraging areas (larger home ranges). Thus, the effects of region (MAV vs. UCP) and age class (adult vs. immature) and the region-by-age class interaction on home range size and core use area of PTT-marked cormorants were tested using analysis of variance (ANOVA). Because variances among region and age class groups were not equal, a heterogeneous variance model structure (Littell *et al.* 2006) was incorporated using the MIXED procedure in SAS (SAS Institute Inc., 2004). With this model structure, a different variance is estimated for each group in the ANOVA, rather than transforming the data for analysis. Furthermore, *F*-test degrees of freedom were corrected for unbalanced variances using the Kenward and Roger adjustment (Littell *et al.* 2006).

Lastly, body mass was hypothesized to affect home range size of cormorants. Although relationships between body size and space use are typically conducted at the species level (Schoener 1968; Harestad and Bunnell 1979), we were interested in knowing whether body size might covary with dominance and influence the quality size of foraging areas. To determine whether body mass influenced the spatial use patterns of PTT-marked cormorants during winter, the body mass of cormorants at the time of capture was related to home range size and core use area using Pearson's correlation coefficient. Significance of all hypothesis tests were assessed using $\alpha = 0.05$.

RESULTS

Mean ± SE home range size and core use area of PTT-marked cormorants wintering in the southeastern U.S. from 1999 to 2001 were 17,490 ± 1,986 km^2 (N = 37) and 1,550 ± 265 km^2 (N = 37), respectively (Table 1). Home range size was highly variable among individuals during winter (Fig. 2), but was not affected by region ($F_{1,2.63}$ = 0.82, P = 0.440), age class ($F_{1,2.63}$ = 1.66, P = 0.299), or their interaction ($F_{1,2.63}$ = 0.63, P = 0.491; Table 2). Similarly, core use area was not affected by region ($F_{1,2.31}$ = 0.86, P = 0.439), age class ($F_{1,2.31}$ = 1.08, P = 0.395), or their interaction ($F_{1,2.31}$ = 0.40, P = 0.582; Table 2). Winter home range size (r = -0.19, P = 0.259) and core use area (r = -0.15, P = 0.372) were not correlated to body mass of cormorants. Mean home range size and core use area of PTT-marked cormorants during summer from 1999 to 2001 was 30,547 ± 6,197 km^2 (N = 6) and 3,124 ± 1,019 km^2 (N = 6), respectively (Table 3, Fig. 3).

DISCUSSION

The winter home ranges reported in this study are more than double the size of the 95% home range (4,609 km^2) and the 50% core use area (566 km^2) reported by Dorr *et al.* (these proceedings) for eastern Lake Ontario cormorants (N = 6) wintering in the southeastern U.S. The reason for this difference is unclear but may have been influenced by the number of observations used to compute each cormorant's home range in

Table 1. Daytime (07.00-18.00 h) home range (95% kernel) and core use areas (50% kernel) of 14 adult and 23 immature (Imm) Double-crested Cormorants marked with Platform Transmitter Terminals PTT transmitters in the Mississippi alluvial valley (MAV) of Arkansas, Louisiana, and Mississippi and the Upper Coastal Plain (UCP) of Alabama during winter (November to February) from 1999 to 2001. N = number of locations.

Cormorant	Age class	Capture region	N	Home range (km^2)	Core use area (km^2)
002	Imm	MAV	56	24,862	1,052
004	Imm	MAV	59	24,130	2,266
005	Adult	MAV	31	17,978	989
006	Imm	MAV	24	15,547	2,419
007	Imm	MAV	24	16,494	1,266
009	Imm	MAV	53	21,296	914
011	Imm	MAV	44	26,793	1,872
012	Adult	MAV	122	38,212	1,900
013	Adult	UCP	39	29,729	3,646
014	Imm	UCP	51	57,998	9,612
015	Imm	MAV	24	10,852	828
016	Imm	MAV	31	12,007	1,586
017	Imm	MAV	22	16,209	1,809
018	Imm	UCP	24	39,680	2,047
020	Adult	UCP	22	8,985	979
021	Adult	UCP	20	6,671	371
022	Imm	MAV	25	16,985	1,664
023	Adult	MAV	21	9,489	1,272
026	Imm	MAV	25	14,805	1,024
027	Imm	MAV	20	8,924	743
031	Imm	UCP	133	1,435	57
032	Adult	UCP	98	12,144	497
033	Imm	MAV	150	40,834	3,351
034	Adult	MAV	181	12,722	489
035	Imm	MAV	81	14,629	922
036	Adult	MAV	161	10,128	1,182
037	Adult	MAV	72	9,244	983
039	Adult	MAV	23	2,639	201
042	Imm	MAV	35	4,206	401
043	Imm	MAV	21	11,832	1,838
046	Imm	MAV	24	14,538	1,347
047	Imm	MAV	24	10,446	728
048	Imm	MAV	24	26,575	3,267
049	Imm	MAV	53	24,481	1,524
050	Adult	MAV	21	5,022	456
38N	Adult	MAV	61	22,820	1,264
38S	Adult	MAV	35	5,789	566
Mean				17,490	1,550
SE				1,986	265

the study by Dorr *et al.* and thus the use of fixed-kernel versus adaptive-kernel estimators for home range analyses. Because the local bandwidth in the adaptive-kernel estimator can be greater in areas with few observations (Kernohan *et al.* 2001), this estimator may have produced larger home ranges than a fixed-kernel estimator, as used by Dorr *et al.* (these proceedings). Another possible reason may be that eastern Lake Ontario cormorants belong to the Atlantic meta-population rather than the Interior meta-population. Only one bird from this study had a summer home range east of central Lake Ontario. Tyson *et al.* (1999) described the eastern boundary of the Interior meta-population as occurring in the extreme eastern part of Lake Ontario. However, researchers now speculate that the boundaries of the Interior meta-population of cormorants should be shifted due to range expansion (Hatch and Weseloh 1999; Chastant 2008).

The similar home range sizes of immature and adult cormorants using the MAV or UCP indicate that irrespective of age, body mass or location, cormorants will utilize a

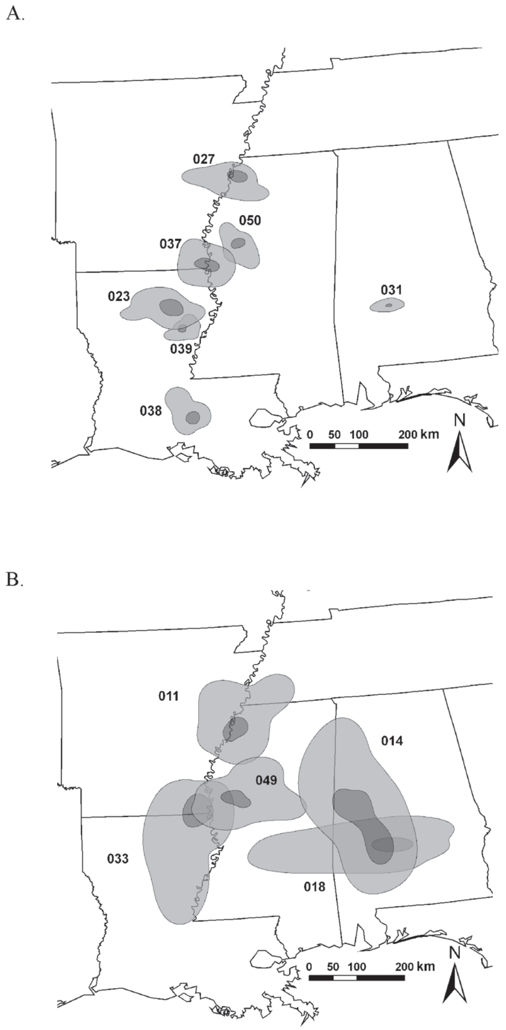

Figure 2. Examples of winter (November to February) daytime (07.00-17.00 h) 95% adaptive kernel home ranges (light shading) and 50% adaptive kernel core use areas (dark shading) of Double-crested Cormorants marked with Platform Transmitter Terminals in the Mississippi Alluvial Valley of Arkansas, Louisiana, and Mississippi and the Upper Coastal Plain of Alabama from 1999 to 2001. A) Home ranges <10,000 km^2 (N = 7), and B) home ranges >20,000 km^2 (N = 5). Numbers represent bird identification.

range size necessary to meet their energetic and social requirements. The cause for the extent of individual variation in home range size (range = 1,435 to 57,998 km^2; Fig. 2) among marked cormorants may have been due to gender or a gender-by-age interaction; unfortunately, gender was not determined for cormorants in this study.

Table 2. Least squares mean daytime (07.00-17.00 h) home range (95% adaptive kernel) and core use areas (50% adaptive kernel) of 14 adult and 23 immature Double-crested Cormorants marked with Platform Transmitter Terminals in the Mississippi alluvial valley (MAV) of Arkansas, Louisiana, and Mississippi and the Upper Coastal Plain (UCP) of Alabama during winter (November to February) from 1999 to 2001. Analysis of variance results are from a heterogeneous variance model with Kenward and Roger-adjusted degrees of freedom. N = number of locations.

		Age Class									
		Adult			Immature						
Response	Region	N	$\bar{x}$	SE	N	$\bar{x}$	SE	Effect	df	*F*	P
Home range	MAV	10	13,404	3,355	20	17,822	1,857	Region	1, 2.63	0.82	0.440
	UCP	4	14,382	5,237	3	33,038	16,663	Age class	1, 2.63	1.66	0.299
								Interaction	1, 2.63	0.63	0.491
Core use area	MAV	10	930	161	20	1,541	180	Region	1, 2.31	0.86	0.439
	UCP	4	1,373	769	3	3,905	2,911	Age class	1, 2.31	1.08	0.395
								Interaction	1, 2.31	0.40	0.582

Table 3. Mean daytime (07.00-18.00 h) home range (95% kernel) and core use areas (50% kernel) of one adult and five immature (Imm) Double-crested Cormorants marked with Platform Transmitter Terminals in the Mississippi Alluvial Valley (MAV) of Arkansas, Louisiana, and Mississippi and the Upper Coastal Plain (UCP) of Alabama during summer (June to August) from 1999 to 2001. N = number of locations.

Cormorant	Age class	Capture region	N	Home range (km^2)	Core use area (km^2)
034	Adult	MAV	69	12,646	262
048	Imm	MAV	32	45,349	5,845
049	Imm	MAV	44	42,792	2,817
052	Imm	UCP	23	24,241	2,559
053	Imm	UCP	25	43,599	6,334
054	Imm	MAV	27	14,654	927
Mean				30,547	3,124
SE				6,197	1,019

The summer home ranges reported here are nearly triple the size of the 95% home range (4,646 km^2 for 2000; 8,119 km^2 for 2001) and the 50% core use area (820 km^2 for 2000; 1,206 km^2 for 2001) reported by Dorr *et al.* (these proceedings) for eastern Lake Ontario cormorants (N = 24). Again, the reason for this difference is unclear but may be due to the reasons noted above.

Similar to some other bird species (Nudds and Ankey 1982; Novoa *et al.* 2006; Rutz 2006), cormorants that migrated to their summer grounds had larger summer than winter ranges. This increase in range size may be attributed to higher foraging and energetic requirements necessary to raise young during the summer. The high densities of prey confined in relatively small areas at aquaculture facilities provide a nearly ideal foraging habitat for piscivorous birds requiring limited energy expenditure to meet energetic requirements (Weseloh and Ewins 1994; Duffy 1995; King *et al.* 1995; King 1996; Glahn *et al.* 1999; Glahn and King 2004). These summer ranges encompassed much of the range of the Interior meta-population of cormorants described by Tyson *et al.* (1999) and Hatch and Weseloh (1999). Dolbeer's (1991) analysis of pre-fledged cormorant banding locations and their subsequent recoveries from the southeastern U.S. showed a similar pattern.

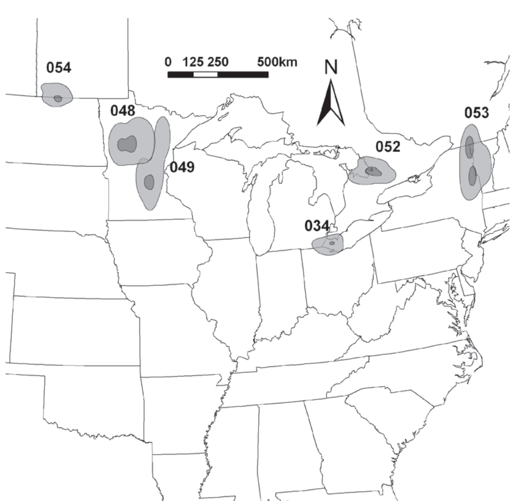

Figure 3. Summer (June to August) daytime (07.00-18.00 h) 95% adaptive kernel home ranges (light shading) and 50% adaptive kernel core use areas (dark shading) of six Double-crested Cormorants marked with Platform Transmitter Terminals in the Mississippi Alluvial Valley of Arkansas, Louisiana, and Mississippi and the Upper Coastal Plain of Alabama from 1999 to 2001. Numbers represent bird identification.

During the winter, most cormorants remained near aquaculture-intensive areas regardless of region, similar to cormorants tracked in earlier VHF telemetry studies (King *et al.* 1995; King 1996; Tobin *et al.* 2002; Dorr *et al.* 2004). Similar to these other studies, most cormorants tend to stay in one general region throughout winter if adequate food resources are available and their roosting sites are undisturbed. However, four (10%) marked birds had large home ranges and were somewhat nomadic (see Methods). Although sample sizes were not adequate for analysis, a few cormorants ranged widely, similar to the few nomadic cormorants noted in earlier telemetry studies (King *et al.* 1995; King 1996).

Future research should be conducted to better understand the summer movements of cormorants remaining in the southeastern U.S. throughout the year. GPS satellite telemetry should be used to determine whether long-term roost harassment and colony management has had an effect on cormorant ranges, habitat use, and activity budgets.

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LITERATURE CITED

Chastant, J. E. 2008. Population characteristics of interior Double-crested Cormorants breeding across the southern border of Ontario. Unpublished M.Sc. Thesis, Mississippi State University, Mississippi State, Mississippi.

Dolbeer, R. A. 1991. Migration patterns of Double-crested Cormorants east of the Rocky Mountains. Journal of Field Ornithology 62: 83-93.

Dorr, B. S., D. T. King, M. E. Tobin, J. B. Harrel and P. L. Smith. 2004. Double-crested Cormorant movements in relation to aquaculture in eastern Mississippi and western Alabama. Waterbirds 27: 147-154.

Dorr, B. S., J. D. Taylor, II, S. J. Werner, D. T. King, J. F. Farquhar, I. M Mazzocchi and R. D. McCullough. (These proceedings.) Movements of satellite marked Double-crested Cormorants from a breeding colony managed by egg-oiling in Lake Ontario, USA. Waterbirds Special Publication 36:1.

Duffy, D. C. 1995. Why is the Double-crested Cormorant a problem? Insights from cormorant ecology and human sociology. Colonial Waterbirds 18 (Special Publication 1): 25-32.

Douglas, D. C. 2000. PC-SAS Argos Filter V2.4 Software Documentation. U.S. Geological Survey, Alaska Biological Science Center, Anchorage, Alaska.

Dunstan, T.C. 1972. A harness for radio-tagging raptorial birds. Inland Bird Banding News 44: 4-8.

Glahn, J. F. and A. R. Stickley, Jr. 1995. Wintering Double-crested Cormorants in the delta region of Mississippi: Population levels and their impact on the catfish industry. Colonial Waterbirds 18 (Special Publication 1): 137-142.

Glahn, J. F. and D. T. King. 2004. Bird Depredation. Pages 503-529 *in* Biology and culture of Channel Catfish. Developments in Aquaculture and Fisheries Science 34 (C. S. Tucker and J. A. Hargreaves, Eds.). Elsevier, Amsterdam, Holland.

Glahn, J. F., P. J. Dixon, G. A. Littauer and R. B. McCoy. 1995. Food habits of Double-crested Cormorants wintering in the delta region of Mississippi. Colonial Waterbirds 18 (Special Publication 1): 158-167.

Glahn, J. F., M. E. Tobin and J. B. Harrel. 1999. Possible effects of catfish exploitation on overwinter body condition of Double-crested Cormorants. Pages 107-113 *in* Symposium on Double-crested Cormorants: population status and management issues in the Midwest. Technical Bulletin No. 1879 (M. E. Tobin, Tech. Coord.). U.S. Department of Agriculture, Animal and Plant Health Inspection Service. Washington, D.C.

Glahn, J. F., D. S. Reinhold and C. A. Sloan. 2000. Recent population trends of Double-crested Cormorants wintering in the delta region of Mississippi: Responses to roost dispersal and removal under a recent depredation order. Waterbirds 23: 38-44.

Harestad, A. S. and F. L. Bunnell. 1979. Home range and body weight - A reevaluation. Ecology 60: 389-402.

Hatch, J. J. and D. V. Weseloh. 1999. Double-crested Cormorant (*Phalacrocorax auritus*) *in* The Birds of North America (A. Poole and F. Gill, Eds.). The Academy of Natural Sciences, Philadelphia, Pennsylvania, and The American Ornithologists' Union, Washington, D.C.

Horne, J. S. and E. O. Garton. 2006. Likelihood cross-validation versus least squares cross-validation for choosing the smoothing parameter in kernel home-range analysis. Journal of Wildlife Management 70: 641-648.

Kernohan, B. J., R. A. Gitzen and J. J. Millspaugh. 2001. Analysis of animal space use and movements. Pages 125-166 *in* Radio tracking and animal populations (J. J. Millspaugh and J. M. Marzluff, Eds.). Academic Press, San Diego, California.

King, D.T. 1996. Movements of Double-crested Cormorants among winter roosts in the delta region of Mississippi. Journal of Field Ornithology 67: 205-211.

King, D. T., K. J. Andrews, J. O. King, R. D. Flynt, J. F. Glahn and J. L. Cummings. 1994. A night-lighting technique for capturing cormorants. Journal of Field Ornithology 65: 254-257.

King, D. T., J. F. Glahn and K. J. Andrews. 1995. Daily activity budgets and movements of winter roosting Double-crested Cormorants determined by biotelemetry in the delta region of Mississippi. Colonial Waterbirds 18 (Special Publication 1): 152-157.

King, D. T., M. Bur and M. E. Tobin. 2000. Capture and telemetry techniques for Double-crested Cormorants (*Phalacrocorax auritus*). Proceedings of Vertebrate Pest Conference 19: 54-57.

Littell, R. C., G. A. Milliken, W. W. Stroup, R. D. Wolfinger and O. Schabenverger. 2006. SAS for mixed models, 2nd ed. SAS Institute Inc., Cary, North Carolina.

Nudds, T. D. and C. D. Ankney. 1982. Ecological correlates of territory and home range size in North American dabbling ducks. Wildfowl 33: 58-62.

Novoa, C., S. Dumas and J. Resseguier. 2006. Home-range size of Pyrenean Grey Partridges *Perdix perdix* *hispaniensis* during the breeding season. Wildlife Biology 12: 11-18.

Palmer, R. S. 1962. Handbook of North American Birds. Volume 1: Loons through Flamingos. Yale University Press, New Haven, Connecticut.

Rodgers, A. R., A. P. Carr, L. Smith and J. G. Kie. 2005. HRT: Home Range Tools for ArcGIS. Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario.

Rudstam, L. G., A. J. VanDeValk, C. M. Adams, J. T. H. Coleman, J. L. Forney and M. E. Richmond. 2004. Double-crested Cormorant predation and the population dynamics of Walleye and Yellow Perch in Oneida Lake. Ecological Applications 14: 149-163.

Rutz C. 2006. Home range size, habitat use, activity patterns and hunting behavior of urban-breeding Northern Goshawks *Accipiter gentilis*. Ardea 94: 185-202.

SAS Inc. 2004. SAS/STAT 9.1 Users' guide. Cary, North Carolina.

Service Argos, Inc. 2001. Argos Users' Manual. Service Argos, Inc., Largo, Maryland. <http://www.argos-system.org/manual/>. Accessed 21 November 2011.

Schoener, T. W. 1968. Sizes of feeding territories among birds. Ecology 49: 123-141.

Tobin, M. E., D. T. King, B. S. Dorr, S. J. Werner and D. S. Reinhold. 2002. Effect of roost harassment on cormorant movements and roosting in the delta region of Mississippi. Waterbirds 25: 44-51.

Tyson L. A., J. L. Belant, F. C. Cuthbert and D. V. Weseloh. 1999. Nesting populations of Double-crested Cormorants in the United States and Canada. Pages 17-25 *in* Symposium on Double-crested Cormorants: population status and management issues in the Midwest. Technical Bulletin No. 1879 (M. E. Tobin, Tech. Coord.). U.S. Department of Agriculture, Milwaukee, Wisconsin.

USDA (United States Department of Agriculture). 1999. Catfish production. National Agricultural Statistics Service, Washington, D.C.

VanDeValk, A. J., C. M. Adams, L. G. Rudstam, J. L. Forney, T. E. Brooking, M. Gerken, B. Young and J. Hooper. 2002. Comparison of angler and cormorant harvest of Walleye and Yellow Perch in Oneida Lake, New York. Transactions of the American Fisheries Society 131: 27-39.

Weseloh, D. V. and P. J. Ewins. 1994. Characteristics of a rapidly increasing colony of Double-crested Cormorants (*Phalacrocorax auritus*) in Lake Ontario: Population size, reproductive parameters and band recoveries. Journal of Great Lakes Research 20: 443-456.

Worton B. J. 1989. Kernel methods for estimating the utilization distribution in home range studies. Ecology 70: 164-168.