DOUBLE-CRESTED CORMORANTS ON SOUTHERN GREEN BAY: ECOLOGY AND FOOD HABITS WITH EMPHASIS ON THE YELLOW PERCH FISHERY, DIETARY OVERLAP WITH SMYMPATRIC AMERICAN WHITE PELICANS, AND SEASONAL CONTAMINANT INTAKE

by

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ABSTRACT

We used new spatially-explicit microclimate and biophysical/behavioral models to estimate the climate/behavior driven daily energy requirements and associated intake of total PCBs and p,p′-DDE by Double-crested Cormorants breeding in Southern Green Bay, WI during 2004 and 2005. The estimated daily energy requirements of breeding adult cormorants ranged from 531 to 1304 kJ/bird/day, which is consistent with existing estimates of cormorant metabolic requirements. Daily food requirement was bounded using the food properties of two predominant dietary prey species, Yellow Perch and Gizzard Shad, as input values. Among years and periods, the resulting daily food requirements had mean estimates of 504 and 815 g wet weight/bird/d for Gizzard Shad and Yellow Perch input values, respectively. Cumulative total PCB intake for a single bird in 2004 ranged from $3.0 \bullet 10^{-6}$ to $4.9 \bullet 10^{-6}$ g/g and from $2.6 \bullet 10^{-6}$ to $4.2 \bullet 10^{-6}$ g/g in 2005. Cumulative p,p′-DDE intake ranged from $2.1 \bullet 10^{-7}$ to $3.4 \bullet 10^{-7}$ g/g in 2004 and $1.8 \bullet 10^{-7}$ to $2.9 \bullet 10^{-7}$ g/g in 2005. Currently, cleanup measures are in place to remove PCBs from the Lower Fox River and Southern Green Bay. This paper supports the role of the cormorant as a bioindicator and proposes that the mechanistic modeling approach used in our study might facilitate the continued use of the cormorant as a model to track remediation efforts, and be expanded to calculate energy

requirements and organochlorine contaminant intake by avian species at different trophic levels in the Southern Green Bay aquatic ecosystem and elsewhere.

INTRODUCTION

The response of Double-crested Cormorants (*Phalacrocorax auritus*, hereafter, referred to as cormorants) nesting in the Green Bay-Lake Michigan (GBLMI) region of Wisconsin to residual organochlorine contamination in the environment has been extensively investigated (Anderson and Hickey 1975, Postupalsky 1978, Heinz *et al.* 1985, Fox *et al.* 1991*a*, Fox *et al.* 1991*b*, Tillitt *et al.* 1992, Yamashita *et al.* 1993, Larson *et al.* 1996, Ludwig *et al.* 1996, Meadows *et al.* 1996, Custer *et al.* 1997, Powell *et al.* 1997, Custer *et al.* 1999, Custer *et al.* 2001,). However, the precise effect of residual contamination on breeding cormorants in this region remains contested. While cormorants continue to exhibit apparent contaminant-mediated reproductive failure, some studies have implicated Planar polychlorinated biphenyls (PCBs) (Tillitt *et al.* 1992), whereas others have pointed to dichlorodiphenyldichloroethylene (DDE), a metabolite of the agricultural pesticide dichlorodiphenyltrichloroethane (DDT) (Heinz *et al.* 1985, Custer *et al.* 1999, Custer *et al.* 2001), or a yet unidentified combination of chemicals present in the aquatic system (Giesy *et al.* 1994).

Cormorants were nearly extirpated from the Great Lakes between the 1940's and early 1970's due to eggshell thinning resulting from elevated levels of DDE in eggs of breeding cormorants (Anderson and Hickey 1975, Postupalsky 1978). Following the ban on DDT in 1972, the Great Lakes cormorant population experienced a dramatic recovery and subsequent growth (Weseloh and Ewins 1994, Weseloh *et al.* 1995) characteristic of a classic population explosion (Ludwig 1984). Within the GBLMI of Wisconsin, cormorants experienced an increase from 7 breeding pairs in 1973 (Matteson *et al.* 1999) to 12,882 pairs in 2005 (USDA Wildlife Services, unpubl. data). Despite the geometric expansion in breeding population over the last three decades, cormorants in the GBLMI have continued to produce eggs with elevated DDE concentrations (Heinz *et al.* 1985, Custer *et al.* 1997, Custer *et al.* 1999, Custer *et al.* 2001). High DDE concentrations have also been observed in sympatric Black-crowned Night Herons (Heinz *et al.* 1985, Rattner *et al.* 1993, Custer and Custer 1995), indicating a persisting local reservoir of DDE in the GBLMI. Recent research suggests residual DDE contamination in the environment may still be affecting breeding cormorants in this region, though to a much lesser extent than characterized historic declines (Custer *et al.* 1999, Custer *et al.* 2001).

Planar polychlorinated biphenyls (PCBs), introduced into the GBLMI via the Fox River, the major tributary to Green Bay, serve as a second source of environmental organochlorine contamination potentially affecting local biota. PCBs were historically produced by paper industries situated along the Fox River and introduced to the aquatic ecosystem as effluent discharge generated from the process of deinking wastepapers (Sullivan, 1983). Though this activity has since ceased (Sullivan 1983), the presence of elevated PCB levels has been identified in sediments (Sullivan 1983, Ankley *et al.* 1992, Manchester-Neesvig *et al.* 1996) and fish (Sullivan *et al.* 1983, Barron *et al.* 2000, Custer *et al.* 2001) in the GBLMI. Accordingly, elevated levels of PCBs have been identified in eggs and chicks of locally nesting piscivorous species including Common Terns (Ankley *et al.* 1993, Hoffman *et al.* 1993), Forster's Terns (Hoffman *et al.* 1987, Kubiak *et al.* 1989, Ankley *et al.* 1993), and Black-crowned Night Herons (Rattner *et al.* 1993, Custer and Custer 1995). Elevated PCB levels have also been measured in the eggs (Tillitt *et al.* 1992, Larson *et al.* 1996, Custer *et al.* 1997), embryos (Custer *et al.* 1997, Custer *et al.* 2001), and chicks (Custer *et al.* 2001) of cormorants nesting in the GBLMI. Further, cormorants nesting in this region produce a high proportion of hatchlings with congenital malformations, such as bill deformities, compared to other locations throughout the Great Lakes (Fox *et al.* 1991*b*, Yamashita *et al.* 1993, Larson *et al.* 1996, Ludwig *et al.* 1996). Although the association between PCB contamination and cormorant deformities has been described as either nonexistent or tenuous (Larson *et al.* 1996, Ryckman *et al.* 1998, Custer *et al.* 1999). PCBs have been identified as the likely causative agent of congenital malformations and developmental anomalies in Common Terns (Hoffman *et al.* 1993) and Forster's Terns (Hoffman *et al.* 1987, Kubiak *et al.* 1989),

In conjunction with the accessibility of ground nests on breeding colonies, the status of the cormorant as an apex predator with an acute sensitivity to environmental DDE makes this species a model candidate for an indicator in biomonitoring programs of aquatic food webs (Fox *et al.* 1991*a*, Somers *et al.* 1993, Ryckman *et al.* 1998). Cormorants are migratory and quickly accumulate organochlorine contaminants present in the aquatic systems surrounding their breeding colonies (Tillitt *et al.* 1992, Yamashita *et al.* 1993, Custer *et al.* 1997, Custer *et al.* 2001). Information on temporal variation of contaminant presence in the local food web may therefore be inferred by examining parameters that influence cormorant contaminant intake across successive seasons.

To better understand how environmental contaminants affect a breeding population, the degree to which the individuals are consuming contaminants should be understood. Spatially- and temporally-explicit models have been used to estimate energy requirements for many species occurring in a variety of ecological contexts based on the physiological response of an individual organism to the environment in which it lives (Porter *et al.* 1973, 1994, 2000, 2002, Kearney and Porter 2004). Previous research has indicated that cormorant diet is contingent upon factors exclusive to a specific system (Ludwig *et al.* 1989, Diana *et al.* 1997, Neuman *et al.* 1997, Glahn *et al.* 1998, Johnson *et al.* 2002, Lantry *et al.* 2002, Rudstam *et al.* 2004), and is thus highly site-specific. Therefore, to estimate contaminant intake and accumulation, a site-specific methodology for estimating the metabolism and associated food requirements of a given cormorant population is required.

Despite the large body of research examining relationships between cormorants and organochlorine contaminants in the environment, the cumulative intake of these contaminants by adult cormorants during a breeding season has received little attention. The present paper uses spatially-explicit models to estimate the energy requirements of cormorants breeding in Southern Green Bay. These values are then used to quantify the intake of organochlorine contaminants p,p′-DDE and total PCBs by cormorants across two breeding seasons. Our intent is to provide a framework for future seasonal contaminant accumulation estimates by situating contaminant intake estimates on a landscape scale (Porter *et al.* 2000, 2002; Kearney and Porter 2004).

STUDY AREAS AND METHODS

Study Area

Microclimate data and physiological parameter estimates were calculated from cormorants nesting on Cat Island (44°34’N, 88°00 W), a 1 ha island located 1 km from the mouth of the Fox River (Figure 1) in Southern Green Bay. The Fox River is the primary source of contaminants introduced into Green Bay from discharge by local paper industries (Bertrand *et al.* 1976). In addition to serving as a breeding colony for cormorants, Cat Island also supports breeding populations of Herring Gulls (*Larus argentatus*), American White Pelicans (*Pelecanus erythrorhynchos*) and Great Egrets (*Egretta alba*). Cormorants nesting in the GBLMI are presumed to overwinter in the lower Mississippi Valley (Dolbeer 1991). Birds typically return to the Cat Island breeding colony in early-mid April and migrate southward around mid-late September. For simplicity purposes, we assumed the breeding season to extend from April 15 to September 15, when the entire breeding population is likely in Southern Green Bay.

Foraging Distribution

Custer and Bunck (1992) found that only 1% of cormorants breeding on Cat Island foraged outside of Green Bay at inland lakes and ponds. Consequently, all prey items consumed by cormorants in this study were assumed to have been removed from Southern Green Bay.

Breeding Phenology

The cormorant breeding season is composed of a 21 d arrival/nest-building/laying phase (Mitchell 1977), a 25 d-28 d incubation phase (Lewis 1926, Mendall 1936, Hanbidge and Fox 1996), and a 56 d chick rearing phase (Mendall 1936). Thus we divided the breeding season of cormorants on Cat Island into the following corresponding periods (15 April-6 May), (7 May-2 June), (3 June-28 July). A fourth phase constituting chick independence/pre-migration (29 July-15 September) was also included to estimate energy values for cormorants following the fledging of chicks. This estimated timing of breeding events is similar to that observed by Custer and Bunck (1992) for Cat Island and Spider Island, another breeding colony in the GBLMI.

Diet Composition

Stomach-content analysis was conducted on 436 birds in 2004 and 540 birds in 2005 that had been collected for a food habits study. Cormorants were collected near Cat Island using 12 gauge shotguns loaded with non-toxic steel shot. Birds were shot as they were returning to the breeding colony, presumably after foraging. Most birds were collected from Longtail Point, a 3.2 km-long sand spit approximately 2.5 km north of Cat Island, and from multiple locations within 1 km of Cat Island.

Energetics and Food Intake

We used the latest version of a microclimate model, Micro2006b, and endotherm model, Endo2006, whose bases are described in Porter *et al.* (1973, 1994, 2000, 2002, 2006) and Kearney and Porter (2004). We used as input data specific limited physiological and behavioral ecology data and morphological/spectral data from museum and dead specimens from the food habits study. We used the model output to address ecological and conservation related questions about a species that otherwise are difficult or impossible to quantify. Models estimated the daily energy requirements for a single adult cormorant for the Julian day at the center of each week of the breeding season. Daily estimates were expanded to weekly estimates, which were summed across the breeding season to predict total energy requirement.

Temporal 2m shade air temperatures and other climate data were obtained from the Green Bay weather station located at 44^{0} 34' N. latitude and 88^{0} 0' W. longitude at an elevation of 175 m. Water temperature was estimated from the southernmost Green Bay water surface temperature taken from Seagrant Coastwatch Sturgeon Bay Surface Temperature images that were obtained through the Coastwatch website (www.coastwatch.msu.edu). The solar radiation calculations for clear sky conditions were computed from SOLRAD, a first principles solar radiation model (McCullough and Porter, 1971) embedded in Micro2006b. Wind speeds for each pixel were assumed constant over 24 hours at the average wind speed for that date. Humidity for each pixel ranged from 89-100% at sunrise and declined from there assuming constant mass of water vapor in the air depending on the maximum measured day's temperature assumed to occur at one hour after solar noon according to equations describing the properties of air (Tracy *et al.* 1973).

Microclimate Model

The microclimate model creates two output files for maximum sunlight/minimum shade; METOUT, SOIL, and two output files for minimum sunlight/maximum shade; SHADMET, SHADSOIL. The endotherm model uses the default location (maximum sunlight) in the available range of microclimates unless heat or cold stress forces a behavioral change to a more favorable local microenvironment. The net effect is that the program tends to minimize energetic heat and mass requirements and maximize activity time by using all four files of microclimate model output for each pixel. User-defined behavioral properties, such as "no burrow" restrict behavioral options to aboveground environments in the case of these birds. METOUT defines the hourly microclimate from the ground surface to 2 m above the ground surface assuming a turbulent boundary layer. Temperatures above 2 m are assumed to vary little from those at 2m height. SOIL defines the hourly microclimate from the ground surface to 2 m below the ground surface defined in METOUT. SHADMET defines the hourly microclimate from the ground surface to 2 m above the ground surface, assuming the maximum shade for a given pixel with its vegetation type, and computes soil surface temperatures and air temperature and velocity profiles above the ground accordingly.

SHADSOIL defines the hourly maximum shade microclimates available from the ground surface to 2 m below ground. A sample input file is Table 1 in the appendix.

Endotherm Model

The endotherm model, Endo2006, with its integrated porous insulation model has been described in detail in Porter *et al.* (1994, 2000, 2002). Briefly, coupled heat and mass balance equations are solved using a numerical guessing routine, Zbrent, as described in Numerical Recipes (2006). The nonlinear equations containing infrared radiation and evaporation terms have no analytical solution. Numerical methods are necessary for maximally accurate solutions.

The equations that are solved are simply

Heat Balance (W):

$$Q_{in} + Q_{gen} = Q_{out} + Q_{st}$$

Mass Balance (g/d)

$$m_{in} = m_{abs} + m_{out}$$

For the heat balance calculations the mass of the birds is small, so we assumed steady state because of the relatively short time constant they have (Porter and James 1979). Thus, $Q_{st} = 0$. Heat in, Q_{in}, is the sum of the combined direct, diffuse solar and infrared radiation fluxes from the sky, the ground and local vegetation (Porter and Gates 1969). Heat out, Q_{out}, is a combination of heat loss by *distributed* respiratory evaporation using the average torso temperature determined by integration from the center of the torso to the skin, convection of heat from the surface of the insulation and evaporated water from the skin, conduction through the air and feather fibers of the porous insulation, and infrared radiation from the porous insulation from the back and the belly, to the sky, vegetation, and ground (Porter et al., 2006, Fig. 2). The relative proportions of these dorsal and ventral radiant heat fluxes are determined by configuration factors (Siegel and Howell 2001).

The *distributed* heat generation term, $Q_{\mathbf{gen}}$, (Porter *et al.* 1994) links the heat and mass balances (Porter et al., 2006 Fig. 3). The "chemical fire" of the body requires both fuel and oxygen. The daily integration of calculated hourly heat energy required to maintain core temperature requires that a specified mass of fuel and oxygen be available. The proportions of protein, fat, and carbohydrate in the diet determine the mass of food that must be absorbed for a particular diet. Thus mass that must be absorbed daily, $m_{\mathbf{abs}}$, from the gut can be calculated. If the animal is hibernating, the amount of fat burned by the body, - $m_{\mathbf{stored}}$, (Porter et al., 2006, Fig. 1), and the water produced by the oxidation is similarly computed. Required daily food intake is computed by knowing the digestive efficiency of a particular diet composition. These numbers are typically available in the literature for a wide variety of diets (Bjorndal, 1990, McWhorter and Del Rio 2000, Whalen and Brown, 2005). Thus, required daily intake of mass can be calculated to maintain body weight. The daily mass balance of the gut can be determined from basic principles, since calculating the required intake and the absorbed mass allows by difference the mass out of the animal's gut. This is important because if there are contaminants or pathogens in the food or water consumed, daily dosages can be computed across a landscape scale.

A similar rationale applies to a mass balance of the respiratory system. Instead of digestive efficiency, oxygen extraction efficiency needs to be known. This is well established for mammals (~24%), birds (~31%) (Hainsworth 1981). Bird oxygen extraction efficiency may vary diurnally and seasonally from 10% to more than 40% (Arens and Cooper 2005). Reptiles can vary between ~6-12% (Klein *et al.* 2003) depending on breathing rate and exercise level. We assumed 34% oxygen extraction efficiency for Double crested cormorants. Each diet type requires a slightly different amount of oxygen depending on its composition. This specifies how much oxygen must be extracted from the respiratory surfaces on a daily basis. A molar balance on the respiratory system allows calculation of the mass of air that must flow through the respiratory system on a daily basis to meet the demands of the "chemical fire". Since the air will be saturated with water vapor in the lungs, a knowledge of the incoming humidity of the air, its incoming temperature, the average body temperature as integrated from core to skin, and required total daily mass flow allows calculation of water lost from the respiratory system if the exit temperature is known or can be estimated based on environmental conditions and the animal's exit respiratory surface properties (Welch, 1980).

Discretionary energy is calculated as the difference between a user-defined level of field activity and resting metabolism needed to maintain body temperature. Based on doubly labeled water data from Nagy (1987, 1994) these differences might be 2.5 - 3.2 times resting levels under field conditions.

Daily food requirements are computed from the total heat energy requirements of the bird for resting and activity (J/d) divided by the caloric value of the diet (J/g of dry food). Water content of the food is considered to be absorbed by the animal. Metabolic water production is added to the food water intake. The difference between mass of water intake and mass of water lost for the day determines the amount of drinking water required for the day. Hourly foraging rates are calculated based on the calculated food requirements for the day divided by the number of hours of activity in a day.

Activity hours are calculated based upon the diurnal/crepuscular/nocturnal habits specified by the user, the hours of skylight when the sun is below the horizon and hours of sun above the horizon calculated in SOLRAD, and the number of hours of activity that might be lost due to heat stress. Additional details of program operations can be found elsewhere (Porter and Mitchell 2003)

Endotherm Model Data Input

Morphological properties of Double crested cormorants were obtained from specimens in the Zoology Museum, U.W. Madison and from carcasses collected from Cat Island, south end of Green Bay. A body mass of the specimen of 3.0 kg was used in the calculations. An ellipsoid body shape was assumed according to the descriptions in Figure 8 in Porter *et al.* (2000). Double crested cormorants feather length was 28.0 mm mid dorsally and 41 mm mid ventrally. Plumage depth was 8 mm mid dorsally and 5 mm mid ventrally. Reflectivities dorsally were 13.4% and ventrally 15.5% as measured by a portable ASD spectrophotometer with grating based optics using a contact probe with a 1 nm resolution from 350-2500 nm. A wavelength range of 350-2500 nm constitutes approximately 97% of the sunlight that reaches the earth's surface. We also measured their reflectivites and feather properties in the Zoology Museum at the University of Wisconsin, Madison with a Beckman DK-2A spectroreflectometer (Porter 1967) that uses prism based optics over the wavelength range 290 – 2600 nm, a wavelength range that includes 98% of the solar radiation reaching the earth's surface. Spectral resolution is greatest at the shortest wavelengths (~ 1 –3 nm) and ~ 10 nm in the near infrared. Agreement between the two measuring devices was 1-2% difference when integrated over the solar spectrum.

Physiological properties were assumed to be those of other modern birds: 40° C. body temperature with a maximum of 42° C with heat stress (Grémillet and Plös 1994, Grémillet *et al.* 1998). An *effective* flesh thermal conductivity of 0.5 W/m-C was assumed based on *in vivo* measurements of muscle tissue (Cheng and Plewes 2002). We assumed an oxygen extraction efficiency of 34% from the respiratory system. A digestive efficiency of 77.6% was assumed for all days of the year for an average fish diet (Brugger 1993). Elevation of metabolic rate above basal was assumed to be 2.0 times basal for non reproductive intervals and 4.90-4.98 times basal for reproductive intervals. Basal metabolic rates were computed based on the heat generation needed to maintain the core temperature at 40°C - 42°C and subject to the morphological properties of the Double crested cormorants and the physical environments available to it, and its' behavioral choices at each pixel on the landscape. It was assumed to be in the open with minimum shade unless it was heat stressed.

Skin water loss is constrained by 1) the current skin temperature, which determines saturation vapor density for the effective wet skin area assumed to function as a free water surface, 2) free stream (outside the boundary layer) air temperature, 3) relative humidity, 4) wind speed, 5) body diameter, 6) plumage depth and 7) body geometry, which determine boundary layer thickness and moisture transport to the free stream air. It was assumed that 1% of the skin functions effectively as a free water surface under resting, non-heat stress conditions.

Double crested cormorants subsist on a diet of fish. Stomach content analysis indicated that Gizzard Shad (*Dorsoma cepadianum*) and Yellow Perch (*Perca flavescens*) were important prey items for cormorants breeding in Southern Green Bay, collectively composing 24% and 29% percent of total biomass consumed in 2004 and 2005, respectively. Gizzard Shad have a body composition of 55% protein, 25% lipid, and 75% water (Strange and Pelton 1987), whereas that of Yellow Perch is 65% protein, 6% lipid, and 78% water (Tanaisichuk and Macay 1989, Hayes and Taylor 1994). As these two species were both predominant prey items in cormorant diet, and differ in body composition, both species were used in calculating energetics estimates. We used these values to compute grams of food required to meet the metabolic demands calculated from the integrated day's heat and mass balance of the cormorants. Water loss rates from the respiratory system were based on the calculated air volume that must pass through the lungs on a daily basis to meet the day's integrated metabolic demands at each pixel on the landscape. We assumed air saturated with water vapor in the lungs at the average body temperature integrated radially from the core to the skin. Exhaled air was assumed to be 2° warmer than local air temperature at each hour.

Cormorants were assumed to be diurnal and not nocturnal or crepuscular. They were assumed to not seek ground shade, nor to seek vegetative shade at night to stay warmer, to be active in the shade in the daytime, and to rest in a cup shaped nest at night with an outer diameter of 0.46m, a wall thickness of 0.188m and nest material thermal conductivity of 0.25W/(m-C). A sample input file is in Table 2 in the appendix.

Endotherm Model Tests

All models contain assumptions and must be tested against known data to assess how well they function. We have tested our model against known laboratory determined physiological data on birds from sparrows to ostriches for resting metabolism and on the African parrot (*Agapornis roseicollis*) from -25 to 40C (Porter *et al.* 2000), and across a temperature range of 10 - 38C for two species of Hawaiian honeycreepers: the Amakihi (*Loxops virens*) and the Anianiau (*Loxops parva*) (MacMillen 1974, Porter *et al.* 2006).

Finally, we also compared predicted food consumption to meet metabolic demands for cormorants based on climate driving local microclimates on Cat Island and cormorant properties. Calculations for both metabolic heat production and respiratory water loss assume a uniform heat production and heat loss per unit volume (a *distributed*, not point source of heat generated and lost, which affects the accuracy of solutions; Porter *et al.* 2000). It was assumed that the birds begin to respond to heat stress when the difference between core and skin gets smaller than 0.5C. The birds are assumed to try to maintain at least a minimum temperature difference between core and skin to assure sufficient radial transport of heat generated by metabolism.

The birds are assumed to dive 6 times per day based on field observations (Mendall 1936, King *et al.* 1995). Dive duration was estimated by dividing the number times cormorants dive per day by total time spent diving estimated by a time budget of cormorants breeding on Lake Champlain (Fowle 1997). Cormorants were therefore assumed to dive every other hour from 0600 hours through 1800 hours for 0.28 - 0.308 hours. Water temperatures range from 12.2 C - 22.5 C depending on the Julian day at depths of 3 m. They swim at a speed of 1.5 m/s (Schmid *et al.* 1995). Cormorant feathers are only partially wetted when they swim (Gremillet *et al.* 2005). When underwater, the feathers retain an air volume of approximately 0.17 m^3 air/kg or 0.00051 m^3 for a 3 kg bird We estimate an ellipsoid shaped skin surface area of 0.215 m^2. From this information we estimate an air layer thickness in the feathers of approximately 2.03 mm next to the skin. If correct weight is 2 kg instead, we have 0.00034 m^3 for a 2 kg bird. Estimated skin surface area is 0.1641 m^2 and air thickness of 2.07 mm next to the skin. The porous media model applies between the skin and the air layer thickness in the feathers. Beyond the air layer in the feathers the environmental boundary conditions become the water temperature and swimming speed. Only conduction and infrared radiation occur in the air layer trapped in the feathers underwater and convection heat transport occurs at the air-water boundary in the feathers underwater.

Sensitivity Analysis

Preliminary ± 10% sensitivity analysis indicated that the models were most sensitive to body composition of prey items. Therefore, to provide a range of potential consumption estimates, the previously described Gizzard Shad and Yellow Perch food properties were used to calculate upper and lower bounds for consumption estimates. Model estimates were identified as being calculated using Gizzard Shad food properties (GISHFP) or Yellow Perch food properties (YPERFP) input values. Selected microclimate and endotherm parameters were also varied by using minimum and maximum recorded values, or varying parameters ± 10% when minimum and maximum values were not available. Sensitivity analyses were conducted to examine the robustness of the models to perturbation and to identify parameters have the greatest effect on daily energy requirements.

Organochlorine Contaminant Intake

A total PCB concentration of 1.6 μg/g wet weight and p,p'-DDE concentration of 0.11 μg/g wet weight of prey items were taken from Custer *et al.* (2001) for pooled samples of fish regurgitated by nestling cormorants on Cat Island. Cumulative contaminant intake curves were produced by multiplying the weekly food requirement of a cormorant by the estimated contaminant concentration, converting the resulting value to g/g wet weight, dividing by cormorant mean body weight, and summing contaminant intake for the period preceding each week through the entirety of the breeding season.

RESULTS

Energy Requirements

All estimates of organochlorine contaminant intake are presented on a wet weight basis. Daily metabolism and food requirement estimates for cormorants with wet and dry plumage varied by ± 1%. Due to this small difference, the metabolic requirements of an individual are given for dry plumage estimates. Adult and hatch year metabolism exhibited some temporal variability, with the largest requirement occurring during the arrival period and the smallest occurring during the last few weeks of the chick rearing period in both 2004 and 2005. The mean metabolic requirement among years and periods was 840 kJ/bird/d (range: 531-1304 kJ/bird/d, Table 1). Using GISHFP input values, the mean daily food requirement estimate among years and periods was 504 g/bird/d (range: 209-908 g/bird/d); this estimate was lower than 815 g/bird/d (range: 338-1468 g/bird/d) estimate derived using YPERFP input values (Table 2, Table 3).

Sensitivity Analysis

As previously mentioned, the models were most sensitive to changes in body composition of prey items. In addition to food properties, the models indicated that core temperature, activity times basal, air temperature, and wind speed had the greatest impact on daily energy requirements (Table 4).

Contaminant Intake

Estimated mean weekly total PCB intake by a single adult cormorant in 2004 was as follows: GISHFP: $3.0 \bullet 10^{-6}$ g/g/week, YPERFP: $4.9 \bullet 10^{-6}$ g/g/week (Figure 2). In 2005 estimated mean total PCB intake by an adult was: GISHFP: $2.6 \bullet 10^{-6}$ g/g/week, YPERFP: $4.2 \bullet 10^{-6}$ g/g/week (Figure 3). Weekly mean intake of p,p'-DDE by an adult cormorant in 2004 was: GISHFP: $2.1 \bullet 10^{-7}$ g/g/week YPERFP: $3.4 \bullet 10^{-7}$ g/g/week (Figure 4). In 2005 mean p,p'-DDE intake by an adult was: GISHFP: $1.8 \bullet 10^{-7}$ g/g/week, YPERFP: $2.9 \bullet 10^{-7}$ g/g/week (Figure 5).

DISCUSSION

Energy Requirements

The daily metabolic requirement values for cormorants breeding on Cat Island in Southern Green Bay, WI, as predicted by the Endo2006 and Micro2006b models, were lower than some estimates derived from existing general allometric equations for avian species. The allometric equation of Birt-Friesen *et al.* (1989) for calculating metabolic rates of free-living seabirds estimates a requirement of 1734 kJ/bird/d for a 2.0 kg cormorant, and that of Nagy (1987) for seabird metabolism predicts 1805 kJ/bird/d. However, our estimates were similar to the daily metabolic requirement of 782 kJ/bird/d predicted by the equation of Kendeigh (1977) for a 2.0 kg breeding non-passerine.

When compared to estimates for other Phalacrocoracids, metabolic rate estimates of this study were intermediate to existing estimates. For similarly-sized breeding Great Cormorants (*Phalacrocorax carbo sinensis*), Grémillet *et al.* (1995), estimated a daily energy requirement of 969 kJ/bird/d for an incubating cormorant, and chick rearing range of 1264 to 2353 kJ/bird/d for a cormorant rearing two small and downy chicks, respectively. In a later study, Hennemann (1983) estimated a range of 786 to 853 kJ/bird/d for captive Double-crested Cormorants with an assumed weight of 1.33 kg. Derby and Lovvorn (1997) estimated 0.643 kJ/g/d for cormorants breeding in Wyoming. Based on this estimate, the equivalent daily consumption by Cat Island cormorants would be 1286 kJ/bird/d.

Our energy requirement estimates were lower than some published values. Grémillet *et al.* (2003) utilized a method that incorporated both diving energetics values and a time-energy budget model to calculate energy requirements. The methodology of Grémillet *et al.* (2003) is the most similar to that employed by this study, and estimated the daily net metabolic requirement of a wintering Great Cormorant with an assumed body mass of 3.2 kg as 3582 kJ/bird/d. This equates to 0.89 kJ/g/d, which produces a metabolic estimate of 1786 kJ/bird/d for a cormorant breeding on Cat Island, 22% greater than our upper estimate of metabolic requirement. Deriving energy estimates from cormorants wintering in the Mississippi Delta, Glahn and Brugger (1995) estimated a mean daily energy budget of 0.82 kJ/g/d, which equates to 1640 kJ/bird/d for Cat Island birds. Dunn (1975*a*) estimated a daily energy requirement of 2072 kJ/bird/d for cormorants breeding in Maine, one of the higher estimates for Double-crested Cormorants. Although the aforementioned studies produced estimates of metabolic requirement higher than those of this study, our estimates are likely a reflection of the unique feeding ecology of the Cat Island population of cormorants. Cormorants breeding on Cat Island tend to forage in close proximity to the colony in shallow, typically warm water. Consequently, Cat Island birds require less energy than other breeding populations that must travel longer distances or forage in deeper, cooler water to obtain prey.

Food requirement estimates derived using GISHFP input values more often fell within the range of existing estimates than did those calculated using YPERFP, indicating that GISFP values might better reflect daily food requirement. Daily food intake estimates for the White-breasted Cormorant (*Phalacrocorax lucidus*) ranged from 16% (Junor 1972) to 20% (du Plessis 1975) of an individual's body weight/d. The equivalent range for a 2.0 kg Cat Island cormorant is an intake between 320 and 400 g/bird/d. Though both estimates are low relative to most produced using YPERFP input values, both fall well within the range estimated using GISFP input values, particularly those for the chick independence/pre-migration period. Dunn (1975*a*) estimated breeding adult Double-crested Cormorants to consume between 20-25% of their body mass/d, equivalent to a range of 400-500 g/bird/d for Cat Island cormorants. Similarly, Glahn and Brugger (1995) estimated a mean daily food intake of approximately 22% of adult body mass/d, and Weseloh and Casselman (1992) estimated a daily intake of 25% of body mass/d. Again, while these projections fall within the range of YPERFP estimates, they are at the low end of produced values. However, they fall neatly within the GISFP estimated values. Grémillet *et al.* (1995) estimated a daily food requirement of 238 g/bird/d for an incubating female and 588 g/bird/d an adult rearing two chicks. While the chick rearing estimate by Grémillet *et al.* (1995) occurs within the ranges of both GISHFP and YPERFP estimates, the incubation estimate is lower than the majority of values for either. Further, the daily food requirement throughout the entirety of incubation as estimated by Grémillet *et al.* (1995) was less than the weight of individual fish identified during stomach content analysis on a regular basis, and is thus an unrealistic estimate for comparison to estimates of this study. Although Grémillet *et al.* (2003) estimated daily metabolic requirement to be 3582 kJ/bird/day, the associated daily food intake by wintering Great Cormorants was estimated to be 441-1095 g/bird/d, considerably overlapping our estimates using both GISHFP and YPERFP input values. As daily food intake is merely a function of climate driven metabolic requirement and energy density of food, apparent similarities in daily food intake where none exist in metabolic requirement are likely a product of differing nutritional values of food items. Prey items consumed by Great Cormorants had higher energetic densities than the Gizzard Shad and Yellow Perch used to estimate daily food requirement for Southern Green Bay cormorants (Grémillet *et al.* 2003).

Estimation of Contaminant Loads in Adult Cormorants

The lack of sibling data with which to compare contaminant concentrations, coupled with the either nonexistent or limited availability of information regarding age, geographic origin, and migratory and overwinter habitats, makes determining organochlorine accumulation rates of adult cormorants during the breeding season highly problematic. Additionally, adult cormorants acquire a portion of their contaminant load in their wintering areas, resulting in a difficult separation of local and extraneous contaminant sources (Postupalsky 1971, Postupalsky 1978). Therefore, using cormorant chicks as a proxy for estimation of adult contaminant accumulation is currently the most pragmatic option. Based on weight of meals and feeding rate of cormorant chicks, Dunn (1975*a*) estimated that the energy intake for an individual chick declines after it has reached 4 weeks of age. Dunn (1975*b*) also observed that at the age of 4 weeks, cormorant chicks reach an asymptotic weight of 1900 g, less than the mean weight of an adult. Dunn (1975*b*) postulated that this weight discrepancy might be attributed to the fact that in the weeks following fledging, cormorant chicks continue to be fed by their parents when accompanying them on foraging trips. The changes noted by Dunn (1975*a*, 1975*b*) might indicate that cormorant chicks begin to exhibit some physiological behaviors of adults following the 4 week age mark. At present, organochlorine contaminant concentration and accumulation rates in cormorant chicks have only been measured in chicks up to 12 d of age. More accurate measurements might be gained by determining and comparing contaminant concentrations in sibling chicks at ages 4 weeks and 5-6 weeks, just prior to obtaining flight. The accumulation rates during this period would likely better reflect those of breeding adults.

PCBs in Southern Green Bay

Due to elevated PCB levels, the Wisconsin Department of Natural Resources (WDNR) issued advisories for public consumption of fish in 1976 and later for wildlife in 1983. In 2003, the U.S. Environmental Protection Agency and the WDNR signed a record of decision outlining a long-term cleanup plan for the Lower Fox River and Green Bay. While the plan includes provisions to monitor levels of PCBs in the sediment, water, and fish tissues, plans to monitor levels in terrestrial vertebrate species are lacking. The findings of Manchester-Neesvig *et al.* (1996) indicated that 50% of the mass of total sediment-bound PCBs are located within 10 km of the Fox River deposition zone, an area encompassing the Cat Island breeding colony. If appropriate accumulation rates for adult cormorants could be estimated, the modeling approach used in this study could provide region-specific, temporally-defined cumulative intake and accumulation rates within and across breeding seasons. Data regarding PCB levels present in avian species in Southern Green Bay have in the past been intermittently generated. To better understand potential fluctuations in PCB presence and associated sources, particularly in response to remediation, consistency in the sampling of a reliable bioindicator is required. The known sensitivity of cormorants to certain contaminants combined with their unique feeding ecology underscores their suitability for this role. As opportunistic, foot-propelled pursuit divers, cormorants are capable of obtaining prey unavailable to non-diving species. They are accordingly able to exploit a prey base that not only reflects local prey presence and abundance, but includes most fish species present within that system. Hence, seasonal accumulation rates of PCBs in cormorants may be used not only to substantiate existing data on PCB levels in fish tissues, but to point to possible impacts on local avian populations as well. Although recent research indicates that PCBs are not a causal factor in the reproductive impairment of cormorants breeding in Southern Green Bay (Larson *et al.* 1996, Ryckman *et al.* 1998, Custer *et al.* 1999, Custer *et al.* 2001), PCBs have been associated with impaired reproduction of Forsters Terns in the area (Hoffman 1987, Kubiak *et al.* 1989). In an egg exchange experiment, Kubiak *et al.* (1989) found that parent Forster's Terns that were fostered eggs from an uncontaminated location had a high incidence of egg disappearance and nest abandonment, leading to reduced hatchability. Kubiak *et al.* (1989) hypothesized that although PCBs may not directly affect egg hatchability, they may be related to aberrant parental behavior and resultantly, reproductive impairment (Kubiak *et al.* 1989). Thus, the cumulative intake and accumulation of PCBs by adult individuals may be of unrecognized importance, further highlighting the need of a method to estimate adult intake and accumulation. Estimating accumulation rates at regular intervals in conjunction with simple food habits analyses might better reveal fluctuations of PCBs in the Southern Green Bay food web, predict their effect upon reproduction of local avian populations, and trace the progress of regional cleanup efforts.

DDE and Reproductive Failure

While the current remediation goal of Southern Green Bay retains a clear focus on PCB concentrations, DDE is the primary organochlorine contaminant implicated in reproductive failure of local avian species. Mean DDE concentrations in eggs of Black-crowned Night-Herons nesting in Southern Green Bay range from 1.44 μg/g (Rattner *et al.*

1993) to 2.2 μg/g (Custer *et al.* 1995). Custer *et al.* (2001) measured a DDE concentration of 6 μg/g in cormorant embryos at pipping from Cat Island. Using DDE concentration of pooled fish samples measured in the same study (Custer *et al.* 2001), we estimated the associated range of mean cumulative DDE intake by an adult cormorant over the course of a single breeding season to be between 3.97 μg/g (GISHFP) and 6.42 μg/g (YPERFP). Custer *et al.* (1999) noted that the 1.0 – 10.8 μg/g range of DDE concentrations measured in cormorant eggs from Cat Island were similar to concentrations that were correlated with impaired reproduction in other species, including Bald Eagles, Snowy Egrets, and Black-crowned Night Herons.

Modeling as a Tool for Understanding Contaminant Transfer

The cormorant's role as a bioindicator is well supported (Fox *et al.* 1991*a*, Somers *et al.* 1993, Ryckman *et al.* 1998). Breeding colonies and nests are often accessible, and feeding ecology and energy intake have been extensively studied (Weseloh and Casselman 1992, Derby and Lovvorn 1997, Diana *et al.* 1997, Glahn and Brugger 1995, Rudstam *et al.* 2004). With the evolving use of modeling in estimating the behavior of an organism in response to its environment, it has become easier to calculate the requirements for species for which there are little such data. Great Egrets, which are morphologically and physiologically similar to Snowy Egrets and currently nest on Cat Island, are a state-listed threatened species in Wisconsin. Consequently, research that requires the destruction of eggs and chicks of Great Egrets is unfeasible. Although the present paper supports the continued pragmatic use of cormorants as an indicator species, this does not preclude the eventual calculation of energy requirement and contaminant intake of sympatric species. Ankley *et al.* (1993) emphasized the importance of understanding contaminant transfer to avian species in the

Southern Green Bay ecosystem. As the energetic requirements of avian species occurring in Southern Green Bay are inextricably linked to the environment in which they exist, any estimates of energetic requirement and associated contaminant intake must acknowledge this relationship. The application of the microclimate and endotherm models to selected avian species, such as the Great Egret, occurring at different trophic levels might better elucidate the accumulation and transfer of contaminants within a food web, leading to more informed conservation, management, and remediation goals.

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Table 1. Metabolism of a single adult and hatch year Double-crested Cormorant in southern Green Bay, WI for the Julian day at the center of each interval week in 2004 and 2005. Values are expressed in kJ/d.

		Metabolism (kJ/d)			
		2004		2005	
Interval week	Julian day (2004/2005)	Adult	Hatch Year	Adult	Hatch year
15 Apr - 21 Apr	109/108	1303	-	1284	-
22 Apr - 28 Apr	116/115	1574	-	1709	-
29 Apr - 6 May	123/122	1515	-	1718	-
7 May - 13 May	130/129	1295	-	1414	-
14 May - 20 May	137/136	1305	-	1459	-
21 May - 27 May	144/143	1290	-	1195	-
28 May - 2 Jun	151/105	1160	-	1054	-
3 Jun - 9 Jun	158/157	1071	-	863	-
10 Jun - 16 Jun	165/164	1008	-	864	-
17 Jun - 23 Jun	172/171	1067	-	890	-
24 Jun - 30 Jun	179/178	1122	-	727	-
1 Jul - 7 Jul	186/185	1022	-	999	-
8 Jul - 14 Jul	193/192	890	-	833	-
15 Jul - 21 Jul	200/199	823	-	727	-
22 Jul - 28 Jul	207/206	881	-	817	-
29 Jul - 4 Aug	214/213	895	888	884	877
5 Aug - 11 Aug	221/220	1130	1120	884	878
12 Aug - 18 Aug	228/227	1105	1096	905	882
19 Aug - 25 Aug	235/234	1123	1114	972	964
26 Aug - 1 Sep	242/241	980	972	927	919
2 Sep - 8 Sep	249/248	995	987	966	957
9 Sep - 15 Sep	256/255	1035	1026	973	964

Table 2. Food Requirement of a single adult and hatch year Double-crested Cormorant on Cat Island, southern Green Bay, WI for the Julian day at the center of each interval week in 2004. Values are expressed in food g wet weight/day.

		Food Requirement (g wet weight/d)			
		2004			
		GISHFP		YPERFP	
Interval Week	Julian day (2004/2005)	Adult	Hatch Year	Adult	Hatch Year
15 Apr - 21 Apr	109/108	335	-	542	-
22 Apr - 28 Apr	116/115	406	-	656	-
29 Apr - 6 May	123/122	390	-	631	-
7 May - 13 May	130/129	857	-	1386	-
14 May - 20 May	137/136	864	-	1397	-
21 May - 27 May	144/143	874	-	1413	-
28 May - 2 Jun	151/105	786	-	1271	-
3 Jun - 9 Jun	158/157	738	-	1194	-
10 Jun - 16 Jun	165/164	712	-	1152	-
17 Jun - 23 Jun	172/171	753	-	1218	-
24 Jun - 30 Jun	179/178	792	-	1280	-
1 Jul - 7 Jul	186/185	722	-	1168	-
8 Jul - 14 Jul	193/192	615	-	995	-
15 Jul - 21 Jul	200/199	570	-	922	-
22 Jul - 28 Jul	207/206	601	-	972	-
29 Jul - 4 Aug	214/213	231	230	374	371
5 Aug - 11 Aug	221/220	291	289	471	467
12 Aug - 18 Aug	228/227	285	283	461	457
19 Aug - 25 Aug	235/234	290	288	469	465
26 Aug - 1 Sep	242/241	246	244	398	395
2 Sep - 8 Sep	249/248	250	248	404	401
9 Sep - 15 Sep	256/255	252	250	408	404

Table 3. Food Requirement of a single adult and hatch year Double-crested Cormorant on Cat Island, southern Green Bay, WI for the Julian day at the center of each interval week in 2005. Values are expressed in food g wet weight/day.

		Food Requirement (g wet weight/d)			
		2005			
		GISHFP		YPERFP	
Interval Week	Julian day (2004/2005)	Adult	Hatch Year	Adult	Hatch Year
15 Apr - 21 Apr	109/108	298	-	482	-
22 Apr - 28 Apr	116/115	421	-	680	-
29 Apr - 6 May	123/122	418	-	676	-
7 May - 13 May	130/129	879	-	1421	-
14 May - 20 May	137/136	908	-	1468	-
21 May - 27 May	144/143	751	-	1215	-
28 May - 2 Jun	151/105	654	-	1057	-
3 Jun - 9 Jun	158/157	571	-	924	-
10 Jun - 16 Jun	165/164	554	-	896	-
17 Jun - 23 Jun	172/171	617	-	997	-
24 Jun - 30 Jun	179/178	509	-	824	-
1 Jul - 7 Jul	186/185	646	-	1045	-
8 Jul - 14 Jul	193/192	531	-	858	-
15 Jul - 21 Jul	200/199	458	-	740	-
22 Jul - 28 Jul	207/206	540	-	873	-
29 Jul - 4 Aug	214/213	221	215	358	348
5 Aug - 11 Aug	221/220	215	214	348	347
12 Aug - 18 Aug	228/227	224	219	363	354
19 Aug - 25 Aug	235/234	232	230	375	372
26 Aug - 1 Sep	242/241	209	208	338	336
2 Sep - 8 Sep	249/248	230	224	371	362
9 Sep - 15 Sep	256/255	224	222	361	359

Table 4. Parameter values used for estimating energy requirements from the Endo2006 and Micr2006b models for an adult Double-crested Cormorant with dry plumage in southern Green Bay, WI using yellow perch body composition estimates, and ranges of parameters used in sensitivity analyses and resulting variation of energy requirements.

Parameters	Min value	Max value	Range	Variation of Seasonal Food Requirement (%)
Endotherm				
Body mass (kg)	1.00	3.00	min-max	± 47
Plumage diameter: Dorsal, ventral (µm)	29.7	36.3	± 10%	± 0.02
Plumage reflectivity: Dorsal, ventral (%)	12, 14	15, 17	± 10%	± 0.03
Plumage length: Dorsal, ventral (mm)	25.2, 36.9	30.8, 45.1	± 10%	± 0.08
Plumage depth: Dorsal, ventral (mm)	7.2, 4.5	8.8, 5.5	± 10%	± 3
Core Temperature (C.)	36.00	44.00	± 10%	± 26
Digestive Efficiency (dec. %)	0.70	0.85	± 10%	± 0
Activity x basal: arrival and chick independence, incubation and chick rearing	1.8, 4.41	2.2, 5.39	± 10%	± 9
Food protein content (%)	0.50	0.60	± 10%	± 5
Food fat content (%)	0.23	0.28	± 10%	± 9
Food dry matter (%)	0.23	0.28	± 10%	± 9
Climate				
Relative humidity maximum (%)	90	100	min-max	< ± 0.01
Relative humidity minimum (%)	35	70	min-max	< ± 0.01
Percent Cloud Cover	0	100	min-max	
Wind speed (m/s)	1.4	3.6	min-max	± 16
Air temperature maximum (C)	13.0	27.9	min-max	± 17
Air temperature minimum (C)	1.6	15.5	min-max	± 23
Dive				
Dive duration: arrival and chick independence, incubation and chick rearing	0.252, 0.277, 0.254	0.308, 0.339, 0.311	± 10%	< ± 0.01
Water Temperature	10.0	24.2	min-max	< ± 0.01
Dive depth (m)	1.0	53	min-max	< ± 0.01

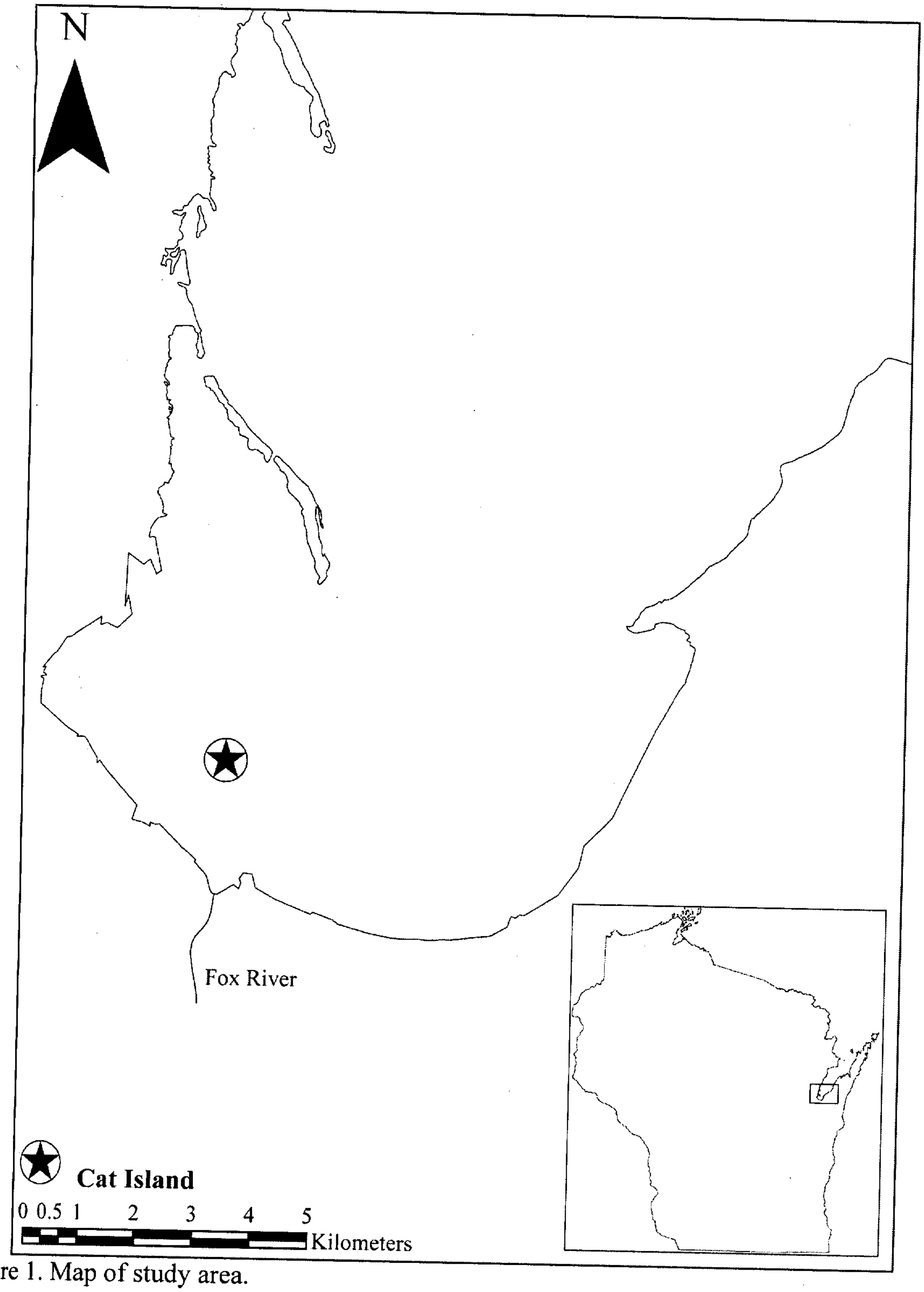

Figure 1. Map of study area.

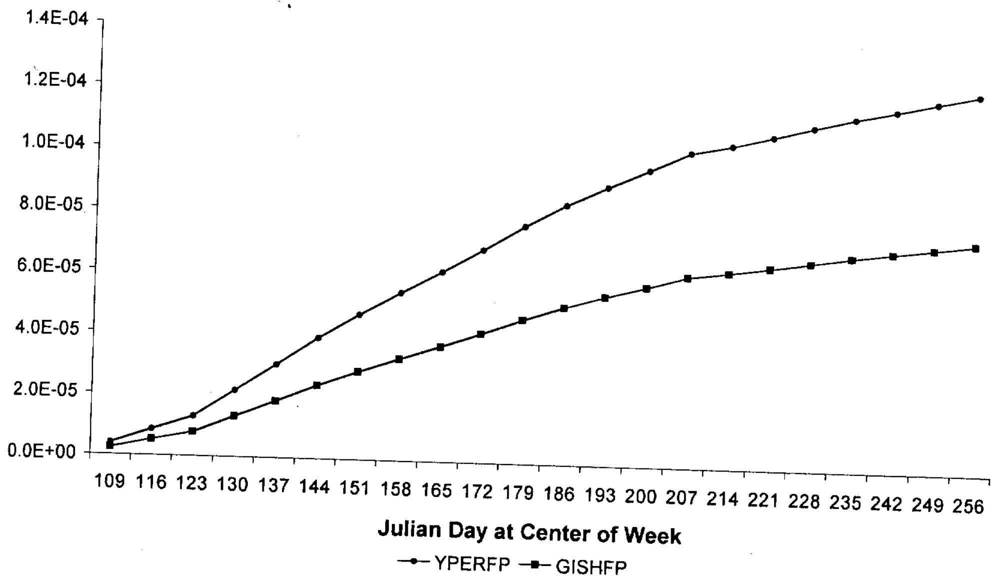

Figure 2. Cumulative PCB intake of a 2.0 kg adult Double-crested Cormorant in Southern Green Bay, WI from April 15 – September 15 2004

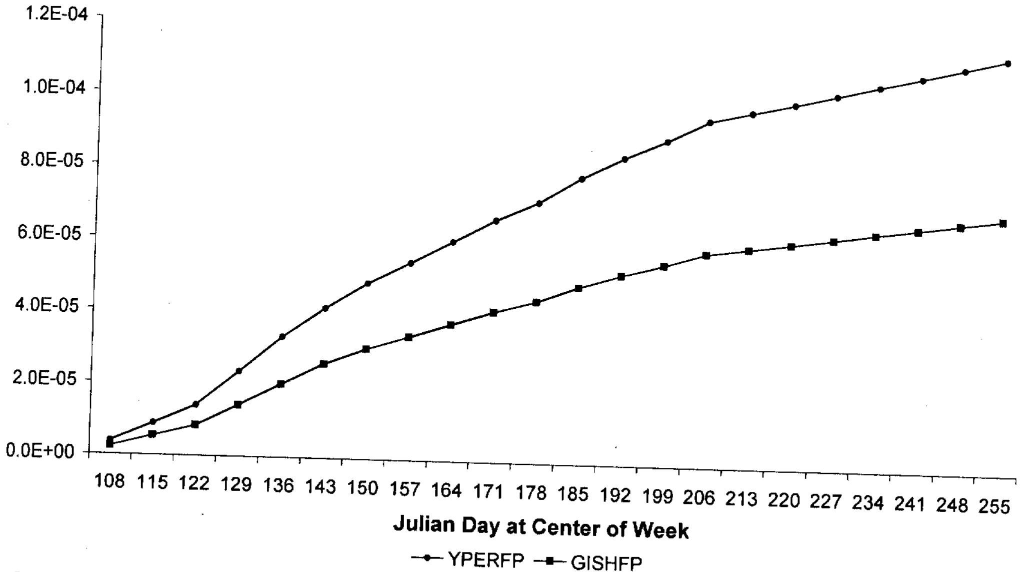

Figure 3. Cumulative PCB intake of a 2.0 kg adult Double-crested Cormorant in Southern Green Bay, WI from April 15 – September 15 2005

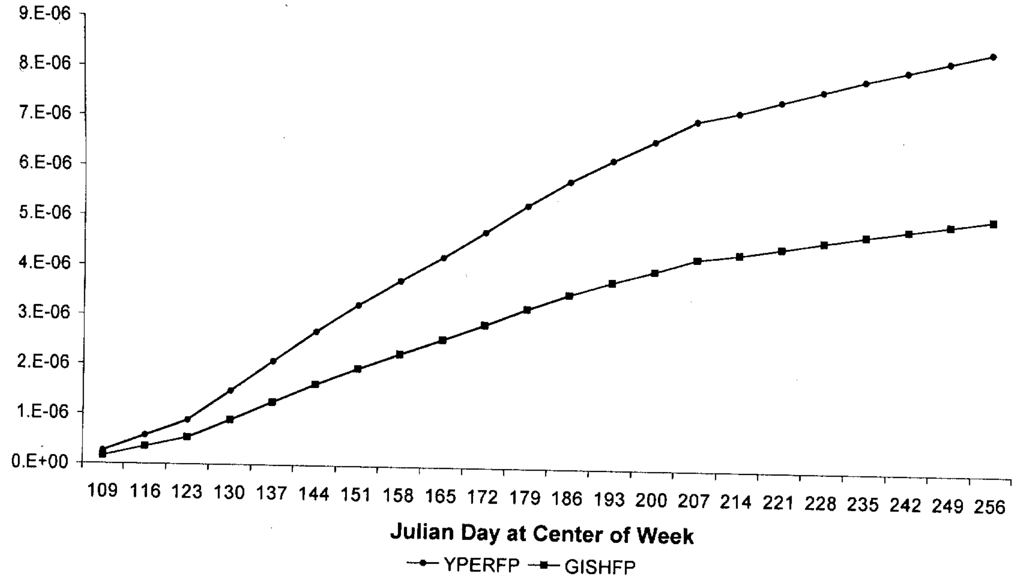

Figure 4. Cumulative p,p'-DDE intake of a 2.0 kg adult Double-crested Cormorant in Southern Green Bay, WI from April 15 – September 15 2004

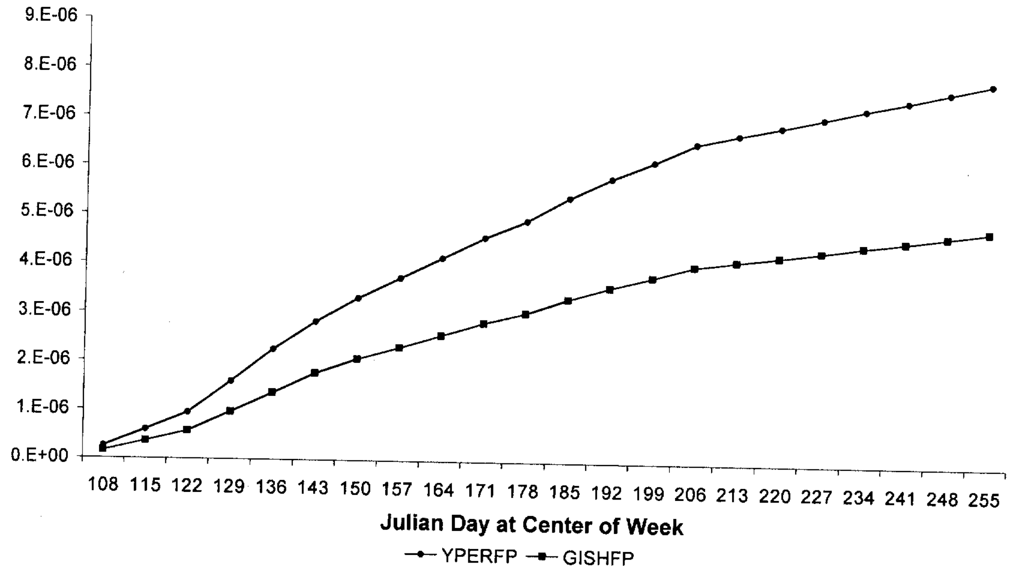

Figure 5. Cumulative p,p'-DDE intake of a 2.0 kg adult Double-crested Cormorant in Southern Green Bay, WI from April 15 – September 15 2005

Appendix I

Table 1. Sample input data file for Micr2006b.

Site Label
Green Bay Weather Sta. H=175m Means of 2005; on SOIL; 0% incremental change in free water surface.

# Julian Days to run (52 max)	Start Julian Day	End Julian Day
22	109	256

Julian days to be run.
109 116 123 130 137 144 151 158 165 172 179 186 193 200 207 214 221 228 235 242 249 256

Roughness height (m)	Soil therm cond (W/mC)	Sub.refl (dec%)	Sub.dens (kg/m3)	Sub.specific heat(J/kg-K)	Sub. longer emiss(dec%)	Integrator error	Animal ave. height (cm)
0.005	0.30	0.30	2000.	855.	0.96	2.	80.

Start interval #	End interval #
1	22

Max's (top row), min's (bottom row) PERCENT SHADE (%) for ave.day each month/interval

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

15 x integer

Hemisphere N=1., S=2.	Latitude (deg) (min)		W Longitude (deg) (min)		Longit.time zone(deg)	Slope (deg)	Azimuth S=0(deg)	Elev. (m)	Cm H2O in air col.
1.	44.	34.	88.	00.	45.	0.	0.	175	0.2

Time of MAXIMUMS (top row), Minimums (bottom row): Air,Wind max's ~ solar noon (integer hours relative to sunrise or solar noon) Rel.Hum,Clouds max's ~ sunrise

Air temp.	Wind speed	Rel. hum.	Cloud cover
1.0	1.0	0.0	0.0
0.0	0.0	1.0	1.0

"Max's (top row), min's (bottom row) REL HUMIDITIES (%) for ave.day each month ***Max=Min+1.0"

96 89 90 97 98 98 97 97 100 91 93 92 95 94 89 95 90 93 90 96 94 92
54 55 46 60 58 68 62 54 70 54 40 62 57 50 35 53 45 41 51 60 53 50

"Max's (top row), min's (bottom row) CLOUD COVER (%) for ave.day each month ***Max=Min+1.0"

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

```
"Max's (top row), min's (bottom row) WIND SPEED (m/s) for ave.day each month  ***Max=Min+0.1"
-----------------------------------------------------------------------------------------------
3.0 3.6 2.5 3.1 3.5 3.1 2.2 3.3 2.6 3.2 3.5 3.0 2.1 2.6 1.4 3.0 3.4 2.3 3.4 2.2 3.1 3.3
3.0 3.6 2.5 3.1 3.5 3.1 2.2 3.3 2.6 3.2 3.5 3.0 2.1 2.6 1.4 3.0 3.4 2.3 3.4 2.2 3.1 3.3

"Max's (top row), min's (bottom row) AIR TEMPERATURE (C) for ave.day each month”
-----------------------------------------------------------------------------------------------
18.5 13.0 14.2 18.8 18.7 16.7 18.0 25.4 22.1 22.4 23.4 22.3 25.6 27.9 26.6 26.6 24.0 23.8 22.7 23.7 25.8 27.2
5.5  1.6  2.1  8.4  9.0  8.3  8.7  12.5 12.3 12.2 10.5 13.3 14.4 15.5 11.3 16.4 11.8 9.8  11.3 12.7 13.7 14.2

Snow or free water presence/absence on surface  'Y'/'N'
-----------------------------------------------------------------------------------------------
'N' 'N' 'N' 'N' 'N' 'N' 'N' 'N' 'N' 'N' 'N' 'N' 'N' 'N' 'N' 'N' 'N' 'N' 'N' 'N' 'N' 'N'

 Substrate absorptivity (decimal %)
-----------------------------------------------------------------------------------------------
 .78 .78 .78 .78 .78 .78 .78 .78 .78 .78 .78 .78 .78 .78 .78 .78 .78 .78 .78 .78 .78 .78

% of surface unit area that acts like a free water surface
-----------------------------------------------------------------------------------------------
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

Table 2. Sample input data file for Endo2006.

```
"Name simulation & input file to run: 'endoprop','endotime', and 'endosens' are choices"
endoprop = no variation in animal parameters with time; read only this file
"endotime = time dependent variables, e.g. core temp., food type available, etc.; "
endosens = sensitivity analysis for different body sizes for given climate regime;
2ND VARIABLE: Hourly output (y/n)? Do not use for GIS-type calc's unless need hourly output
Hourly output = 'y' creates files 'HOURPLOT.OUT' and 'ACTHOURS.OUT'.3RD VAR = 'y'->file OUTPUT printed
"4TH VAR: IF 2.0<DEPEND<3.0 = total metab.in W;if DEPEND=2.0, then metab. in W/kg;"
5TH-7TH variables: 'ECTHRM' vs 'NDTHRM' (Ectotherm vs. Endotherm)=known [Tc-Met rate known; solve for Tc] vs
"[fixed Tc, solve for Met(no flight) OR [fixed Met, solve for Tc (flight). USE 'NDTHRM' IF FLIGHT = 'Y'"
"If 'ECTHRM', then read slope & intercept of ln(ml O2/g/h) = slope*Tc + intercept, ELSE USE ZERO FOR SLOPE AND
INTERCEPT IF NDTHRM"
```

```
'ENDOPROP'  'Y' 'Y'  2.5  'NDTHRM' 0.  0.
```

```
Double Crested Cormorant, Phalacrocorax auritus Adult male dry plumage chick rearing
Animal Variables Dep var form: 2.0<DEPEND<3.0 = total metab.in W
ALLOMETRIC properties
Geometric properties
```

Max "wt "(kg)	Min. wt (kg)	Fat insul thick(m)	Geometric approx.(integer) 1=cyl,2=spher, 3=ellips, 4=lizard	Whole body(torso if apndgs) '0APNDG'if no appendages '2APNDG'if 2 appndg (e.g.bird) '4APNDG'if 4 appndg (e.g.mammal) use complx geom's	% ventral area contacting substr. (decimal %)"	Animal density" kg/m3 (932.9)	User supplied allometry? (Y/N)
3.0	1.0	0.05	3	'0APNDG'	0.0	932.9	'N'

Fur Properties - LEGS Note to user *** use same values for all if modeling as a single lump

Hair dia (um) dsl vntl	Hair length (mm) dsl vntl	Fur depth (mm) dsl vnt	Hair dens. (1/cm2) dsl vntl	fur front_refl nd	fur back_refl nd	fur tran nd
0. 0.	0. 0.	0. 0.	0. 0. 0.0	0.0	0.0	0.0

Fur Properties - HEAD & NECK

Hair dia (um) dsl vntl	Hair length (mm) dsl vntl	Fur depth (mm) dsl vnt	Hair dens. (1/cm2) dsl vntl	fur front_refl nd	fur back_refl nd	fur tran nd
33. 33.	59. 59.	3. 3.	2344. 2344.	0.134	0.155	0.0

Fur Properties - TORSO

Hair dia (um) dsl vntl	Hair length (mm) dsl vntl	Fur depth (mm) dsl vnt	Hair dens. (1/cm2) dsl vntl	fur front_refl nd	fur back_refl nd	fur tran nd
33. 33.	28. 41.	8. 5.	2344. 2344.	0.134	0.155	0.0

PHYSIOLOGICAL properties - temperature and water loss from metabolism & skin

Core min	Core max	diff Tc-Tskin(C)	Texpir-Tair (C)	% skin wet (sweat)	Thermal conductivity of flesh (0.412 - 2.8 W/mC)
40.0	42.0	0.5	2.	1.	.500

PHYSIOLOGICAL properties - lungs and gut: grass hay dig. eff.

O2 extraction efficiency (%)	Gut passage time (days)	Fecal water (dec. %)	Urea in urine (dec. %)
34.	1	0.50	0.20

PHYSIOLOGICAL properties - monthly values: Core temperature regulated this month

This can be used to simulate hibernation or other unusual activity timing.

109	116	123	130	137	144	151	158	165	172	179	186	193	200	207	214	221	228	235	242	249	256
40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40

Physiological properties - Digestive efficiencies - monthly values:

" (decimal %) 0.95-nectar (McWhorter & Del Rio, 2000); 0.85-insects "

109	116	123	130	137	144	151	158	165	172	179	186	193	200	207	214	221	228	235	242	249	256
0.776	0.776	0.776	0.776	0.776	0.776	0.776	0.776	0.776	0.776	0.776	0.776	0.776	0.776	0.776	0.776	0.776	0.776	0.776	0.776	0.776	0.776

PHYSIOLOGICAL properties - monthly values: Times basal for activity energy & food for it (1-7)

This can be used to simulate phenology of food available and reproduction timing.

109	116	123	130	137	144	151	158	165	172	179	186	193	200	207	214	221	228	235	242	249	256
2.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

PHYSIOLOGICAL properties - monthly values: Times basal for disc. nrg food intake (0-7)

Can use to simulate phenology of food available and reproduction timing.0=no reprod effort

109	116	123	130	137	144	151	158	165	172	179	186	193	200	207	214	221	228	235	242	249	256
0.	0.	0.	1.9	1.9	1.9	1.9	1.98	1.98	1.98	1.98	1.98	1.98	1.98	1.98	0.	0.	0.	0.	0.	0.	0.

FOOD properties - % protein (decimal %): monthly values:

" 100%=1.00 Nectar except breeding months, then same as creeper (April-May): "

109	116	123	130	137	144	151	158	165	172	179	186	193	200	207	214	221	228	235	242	249	256
.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65

FOOD properties - % fat: monthly values
(decimal: 100% is 1.00)

109	116	123	130	137	144	151	158	165	172	179	186	193	200	207	214	221	228	235	242	249	256
.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06

FOOD properties - % carbohydrate: monthly values

(decimal format) 100% carbohydrate = 1.00 decimal

109	116	123	130	137	144	151	158	165	172	179	186	193	200	207	214	221	228	235	242	249	256
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

FOOD properties - monthly values: % dry matter

(decimal)(0.25 green veg.;0.75 seed humid stor.; 0.9219 dry seed)

109	116	123	130	137	144	151	158	165	172	179	186	193	200	207	214	221	228	235	242	249	256
.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25

BEHAVIORAL properties - monthly values: Diurnal? ALL BEHAVIOR OPTIONS MUST BE IN CAPS!!!

(Y/N) (Diurnal value for Diurnal in BEHAV.DATA should be the January value here)

109	116	123	130	137	144	151	158	165	172	179	186	193	200	207	214	221	228	235	242	249	256
'Y'	'Y'	'Y'	'Y'	'Y'	'Y'	'Y'	'Y'	'Y'	'Y'	'Y'	'Y'	'Y'	'Y'	'Y'	'Y'	'Y'	'Y'	'Y'	'Y'	'Y'	'Y'

BEHAVIORAL properties - monthly values: Nocturnal?
(Y/N) (Diurnal value for Diurnal in BEHAV.DATA should be the January value here)

109	116	123	130	137	144	151	158	165	172	179	186	193	200	207	214	221	228	235	242	249	256
‘N’	‘N’	‘N’	‘N’	‘N’	‘N’	‘N’	‘N’	‘N’	‘N’	‘N’	‘N’	‘N’	‘N’	‘N’	‘N’	‘N’	‘N’	‘N’	‘N’	‘N’	‘N’

BEHAVIORAL: Burrow OK? (Y/N)	Climb to cool? (Y/N)	Ground shade seeking OK? (Y/N)	Crepuscular activity? (Y/N)	Night shade? (Cold protection) (Y/N)	Dive? Dive option (Y/N)	Active in shade in daytime (Y/N)
'N'	'N'	'N'	'N'	'N'	'Y'	'Y'

"BEHAVIORAL "Flight OK? "(Y/N)	Flight variables If flight = yes, then specify flight metab (W)	If flight is yes, If animal is bee or pollinating insect, average flight load (g) may be specified to correct for flight metabolism	Class of animal (6 letters): 'mammal'," ‘birdie','reptil','amphib', (mammal,bird,reptile, 'insect'",amphibian,ins
'N'	151.0	0	'birdie'

Fossorial(Below "ground only)? (Y/N)	Digger Dig burrows?	" If fossorial, OK node#s=2-10; else use 1 "	Arboreal " exclusively? (Y/N)	Shelter/nest type: CYLN=HOLLOW CYLINDRICAL;HFCL=HOLLOW HALF CYLINDER (FLAT,CUPP,CYLN,HFCL," (Y/N) SPHR,DOME,NONE) SPHR=HOLLOW SPHERE"
'N'	'N'	1	'N'	'CUPP'

BEHAVIORAL properties		Under		Sum of F's must <= 1.0			Seed tray:iced vs
" # feeding periods	# hrs active feed period	/ bush (1) in open (0)		vs Fasky 0-0.5	Fagrd 0-0.5	Fabush 0-0.5	heated,e.g.-4 vs 3 " vs no change (0)
6	1.23	0	0.5	0.4	0.0	0.0	0.0

"NEST properties: if nest THICKNESS = 0.0, no nest is assumed"		Shelter/Nest # animals in nest
Nest wall thickness (m)	Nest wall (wood: 0.10-0.35;sheep wool:0.05) thermal conductivity (W/m-C)	MULTIPLIER to adjust number of individuals present " for added heat production. If <1, no nest calc."
0.188	0.25	3

AIR (Burrow gas properties; atm values in parens) NOTE:THESE MUST SUM TO 100.0%

% O2 (20.95%)	%CO2 (0.03%)	%N2 (79.02%) = standard atmosphere
20.95	0.03	79.02

"SOIL,BURROW properties" Soil type; Finesand=1 sandyloam=2 gravelly sand=3 clay=4	Segment length/day (m)	Burrow depth (m)
3	0	0

Shelter/Nest properties (Hominid Paleoshelter)
Used when nest type is not 'NONE' and multiplier >= 1

Length(m)	Outer diameter(m)	Solar reflectivity(decimal: 1.0 = 100%)

II. DOUBLE-CRESTED CORMORANT ECOLOGY ON SOUTHERN GREEN BAY WITH AN EMPHASIS ON DEPREDATION OF THE LOCAL YELLOW PERCH FISHERY

ABSTRACT

Many sport anglers and commercial fishers regard the Double-crested Cormorant (*Phalcrocrocorax auritus*) population in southern Green Bay as responsible for the sharp declines in the local Yellow Perch (*Perca flavescens*) population during the 1990s. In 2003, after repeated years of low recruitment, the Yellow Perch population produced the largest cohort in 25 years. We utilized this opportunity to investigate food habits of Double-crested Cormorants in 2004 and 2005 with reference to the aging 2003 cohort. Stomach content analyses of 436 cormorants in 2004 and 540 cormorants in 2005 indicated that Yellow Perch were an important component of cormorant diet, and that most perch consumed were of the 2003 year-class. Biomass and number of prey species consumed by the southern Green Bay colony were estimated using spatially-explicit microclimate and biophysical/behavioral models. Although analyses indicated that cormorants consumed more Yellow Perch than were removed from Green Bay by combined sport and commercial harvests, perch consumed by cormorants were primarily non-reproducing individuals or fish not yet of harvestable size. Other important prey species for cormorants included Gizzard Shad (*Dorsoma cepadianum*), which compete with perch for food resources, Round Gobies (*Neogobius melanostomus*), an invasive exotic species, and White Suckers (*Catostomus commersoni*), which are competitors for benthic prey and have previously been associated with reduced body composition quality in sympatric Yellow Perch populations.

INTRODUCTION

Double-crested Cormorants (*Phalacrocorax auritus*, hereafter referred to as cormorants) were first observed nesting on the Great Lakes in the early 1900s, and increased in population until the early 1950's (Postupalsky 1978, Weseloh *et al.* 1995). Reproductive failure associated pesticide contamination in the environment, particularly DDT and its metabolite DDE (Postupalsky 1971, Anderson and Hickey 1972), in conjunction with increased human disturbance, resulted in a more than 80% decline in Great Lakes cormorant populations between 1947 and 1972 (Postupalsky 1978, Weseloh *et al.* 1995). Following the implementation of environmental legislation restricting the use of organochlorine pesticides and reduced persecution by humans, Great Lakes cormorants experienced a dramatic recovery (Ludwig, 1984, Weseloh *et al.* 1995, Matteson *et al.* 1999, Fowle *et al.* 1999). From 1970-1991 populations increased at a staggering 29% annual rate (Weseloh *et al.* 1995).

The first published record of cormorants breeding in Wisconsin described 13 pairs nesting in trees on Lake Wisconsin in 1921 (Stoddard, 1922). From 1921 through the early 1970s, the Wisconsin cormorant population experienced rates of growth and decline consistent with other Great Lakes populations (Matteson 1983, Matteson *et al.* 1999). Concurrent with the reduction of DDT and DDE in the environment, the addition of the cormorant to the Wisconsin Endangered Species List in 1972 and the erection of artificial nesting platforms at 13 locations across the state in 1974 facilitated recovery and subsequent growth of the Wisconsin cormorant population (Meier 1981, Matteson, 1983). From 1973 to 1997 Wisconsin's population of breeding cormorants increased at an annual rate of 25%; cormorants in the Green Bay-Lake Michigan region experienced the highest rates of increase in the state, and accounted for 81 percent of the state's total breeding population by 1997 (Matteson *et al.* 1999). Currently, Wisconsin's inland lakes and islands of Lakes Superior and Michigan contain the second-largest number of breeding cormorants in the U.S. Great Lakes, with highest concentrations of cormorants occurring on Green Bay and Lake Michigan (Wires *et al.* 2001)

Cormorants have historically been associated with real and perceived threats to North American fish resources. By the mid-20th century, a number of studies had examined the food habits of cormorants in relation to their potential injurious economic impacts on populations of sport and commercial fish (Taverner 1915, Lewis 1929, Mendall 1936, Scattergood 1950, Trautman 1951). The rapid increase of cormorant populations that occurred in North America during the latter part of the 20th century was again accompanied by concerns that cormorants were depredating valuable fish resources, prompting further research investigating cormorant food habits in relation to fishery depredations (Craven and Lev 1987, Bur *et al.* 1997, Diana *et al.* 1997, Johnson *et al.* 2002, Lantry *et al.* 2002, VanDeValk *et al.* 2002, Herbert and Morrison 2003, Fenech *et al.* 2004, Rudstam *et al.* 2004). Though a number of such studies demonstrated that primary prey consist of forage fish of little or no commercial value (Craven and Lev 1987, Diana *et al.* 1997, Johnson *et al.* 2002, Herbert and Morrison 2003, Fenech *et al.* 2004), several implicated cormorants in prior declines of sport and commercial fisheries in the northern United States and Canada (Lantry *et al.* 2002, VanDeValk *et al.* 2002, Rudstam *et al.* 2004) as well as in the southern United States (Glahn *et al.* 1995).

Concomitant with the rapid increase in southern Green Bay's cormorant population was a decline in the local Yellow Perch (*Perca flavescens*) fishery, which historically produced the largest perch harvest in Lake Michigan (Kraft 1982). The southern Green Bay Yellow Perch population experienced a 90 percent decline from the late 1980s through 2002 (J. Hasz, pers. comm.), while the local breeding population of cormorants increased over 300-fold at a 19 percent annual rate of increase (Figure 1). In 2003, after repeated years of low recruitment, the Yellow Perch population was punctuated by the appearance of the largest year-class hatched in 25 years. As cormorant diet is a reflection of relative abundance and population dynamics of prey species (Bur *et al.* 1997, Diana *et al.* 1997, Ross and Johnson 1997, Rudstam *et al.* 2004), the 2003 cohort provided a unique opportunity to examine the impact of cormorant predation on a large year-class of a commercially valuable species as it ages. The present study therefore seeks to quantify the effect of cormorant depredation on the southern Green Bay Yellow Perch population, with emphasis on impacts on the 2003 cohort, and a goal of improved management of both cormorants and the perch fishery.

STUDY AREAS AND METHODS

Study Area

The study area boundary extended from the mouth of the Fox River to Peshtigo Point and Sturgeon Bay on the west and east coasts of Green Bay, respectively. The study area was 1080 km^2 and encompassed Cat Island (44°34'N, 88°00 W), a 1 ha island and breeding colony for cormorants, Herring Gulls (*Larus argentatus*), American White Pelicans (*Pelecanus erythrorhynchos*) and Great Egrets (*Egretta* alba) located 1 km north of the mouth of the Fox River (Figure 2). The terrestrial habitats surrounding Green Bay are primarily agricultural land and woodlands. Cat Island was historically part of the Cat Island chain, which was composed of three large islands and eight to ten smaller islands. High water levels in 1973-1974 and a strong storm in 1973 virtually destroyed the Cat Island chain (T. Erdman pers. comm.).

Breeding Phenology

The cormorant breeding season is composed of a 21 d arrival/nest-building/laying phase (Mitchell 1977), a 25-28 d incubation phase (Lewis 1926, Mendall 1936, Hanbidge and Fox 1996), and a 56 d chick rearing phase (Mendall 1936). Thus. we divided the breeding season of cormorants on Cat Island into the following periods: 15 April-6 May, 7 May-2 June, 3 June-28 July, respectively. A fourth phase constituting chick independence/pre-migration (29 July-15 September) was also included to estimate energy values for cormorants following the fledging of chicks. This estimated timing of breeding events is similar to that observed by Custer and Bunck (1992) for Cat Island and for Spider Island, another breeding colony in the Green Bay-Lake Michigan region. Estimated breeding effort associated with each period was incorporated into energetics estimates.

Cormorant Numbers and Reproductive Success

Since 1974, the number of cormorants breeding on the Cat Island chain has been censused every year excluding 1982, 1995, 1996, 1998, 1999, and 2003 (T. Erdman, unpubl. data). The census unit of an apparently occupied nest (AON) employed by Weseloh *et al.* (1995) was used to estimate the breeding populations of cormorants throughout the Great Lakes. AONs were defined any recent aggregation of nesting material, regardless of whether they contained eggs. Because nest structures without occupants frequently serve as sources of nesting material for other breeding cormorants (Weseloh and Ewins 1994), all surveyed nests were considered active. The Cat Island breeding population was estimated during the incubation period by doubling the number of AONs present. Counts were conducted midmorning by selecting a starting location on the island and moving in a counter-clockwise direction until the entire island had been covered. To estimate clutch size and brood survival, 50 nests were marked and the presence and number of eggs and chicks recorded until all monitored nests had fledged. Monitoring of nests in 2004 commenced too late in the breeding season to calculate nest success. Hatching rate and nest success during the 2005 chick rearing period was calculated from methods outlined in Mayfield (1975) and previously used by Custer *et al.* (1999) to estimate Cat Island reproduction. Average clutch size was estimated from completed clutches, which were considered clutches that contained the same number of eggs in consecutive colony visits. Lewis (1929) observed that cormorant chicks to leave their nests by three weeks of age when threatened by an approaching human. Thus, all counts occurring after chicks were three weeks old may be unreliable. Consequently, we assumed all chicks that survived to three weeks of age would survive to fledging and at that time feed at the adult rate for the remainder of the breeding season. To minimize disturbance to breeding American White Pelicans and Great Egrets, a state-threatened species, collection of nest data was restricted to no more than one trip per week. The duration of most visits were less than 30 minutes. To maintain representation of spatial variability, nests were marked along a transect extending from the interior of the island toward its periphery. Growth of chicks was estimated by weighing a sample of 20 chicks during each colony visit until all chicks from marked nests had fledged.

Foraging Distribution

Custer and Bunck (1992) suggested that the majority of cormorants breeding on Cat Island forage within Green Bay. We conducted periodic aerial surveys to further examine the spatial distribution of foraging cormorants within the study area. Aerial survey transects encompassed the entire study area and were spaced at approximately 1.5 km. Transects were created using ArcView 3.2 and uploaded to a hand-held global positioning system (GPS). Numbers, locations, and activity of all observed cormorants either in flying flocks or actively foraging were recorded. Large groups of cormorants were recorded using a digital camera or video recorder and counted later. Surveys were flown by the same pilot in a Cessna 172 at an altitude of 500 ft and a ground speed of 100 mph. Surveys were typically flown from 10 AM and 2 PM to coincide with the period during which most cormorants were collected from the field.

Cormorant Diet Composition

Stomach-content analysis was conducted on 436 cormorants sampled in 2004 and 540 sampled in 2005. From May 13 through September 30, 2004 an average of 19 cormorants was collected per week; from April 28 through September 13, 2005, an average of 26 cormorants was collected per week. A single sample day was typically required to collect the required weekly sample. Cormorants were shot with 12 gauge shotguns with non-toxic steel by USDA Wildlife Services (WS) technicians as they were returning to the breeding colony, presumably after foraging. Most birds were collected from Longtail Point, a 3.2 km-long sand spit approximately 2.5 km north of Cat Island, and from multiple locations within 1 km of Cat Island. Birds collected singly as opposed to in flying flocks may consume larger prey items that require greater time to digest than smaller prey items (Carss 1997). This can result in misrepresentation of cormorant diet, as the more digested the contents of a stomach are, the greater the potential for bias in prey species count or identification. Most cormorants were collected from passing flocks of several to 500 or more individuals. Collections typically took place between 10 AM and 2 PM, a time frame associated with a high occurrence of foraging flights (Mendall 1936). Collected cormorants were weighed and injected with 60 mL of 70% ethanol using a syringe inserted down the esophagus to halt digestion. Tarsus length, unflattened wing chord length, exposed culmen length, and culmen depth were measured. Stomachs were removed either at the U.S. Fish and Wildlife (FWS) Service Office lab in New Franken, WI or in the field, at which time birds were sexed based on identification of internal gonads. All stomachs were placed in cold storage (-20°C) within 5 hours of collection.

Fish from stomachs were identified to species, weighed (wwt), and measured for total length (L). If fish were too digested for measurement, they were assigned the mean length of conspecifics in the stomach or for the sample day. Highly digested remains such as scales and otoliths were excluded from analyses. Allometric equations from Schneider *et al.* (2000) were used to estimate intact wwt of individuals from L measurements for all prey species except Round Gobies, which were estimated using an equation from Phillips *et al.* (2003). The wwts of prey items showing very little decomposition were compared to allometric estimates to assess accuracy in weight estimation. Because average lengths of female Yellow Perch in southern Lake Michigan may be greater than those of males (Wells and Jorgenson 1983), scale samples were taken from Yellow Perch throughout each field season for later aging by Wisconsin Department of Natural Resources (WDNR) fisheries technicians. Because < 1% of cormorants breeding on Cat Island forage on inland lakes and ponds (Custer and Bunck 1992), all prey were assumed to have originated within the study area. The Green Bay Yellow Perch population is genetically distinct from other Lake Michigan perch populations (Miller 2003), indicating a spatial delineation between the two populations. Therefore, all inferences regarding cormorant consumption of perch pertain exclusively to the Green Bay Yellow Perch population.

Fish Consumption Models and Data Analysis

To estimate daily metabolic requirements and associated food intake, we used the latest version of spatially-explicit microclimate and biophysical/behavioral models, Micro2006b, and Endo2006, described in detail in Porter *et al.* (1973, 1994, 2000, 2002) and Kearney and Porter (2004). Modeling methods specific to this study are described in Chapter 1. Daily food requirement (g/wwt/bird/d) was calculated as the quotient of daily metabolic requirement and energy density of food. Preliminary analyses indicated that Yellow Perch and Gizzard Shad were dominant prey items in cormorant diet. These two species differ in body composition (Strange and Pelton 1987, Tanaisichuk and Macay 1989, Hayes and Taylor 1994), and were therefore used to attain a range of daily food requirement estimates. Cormorant food requirements were expressed as estimated using Yellow Perch (YPERFP) or Gizzard Shad (GISHFP) food properties. Daily energy estimates were multiplied by 7 to calculate weekly estimates. The metabolic budget of an adult cormorant included the energy required for reproduction and rearing of young. The energetic requirements of a brood of chicks were incorporated into the estimate of both parents for a period of 8 weeks, after which chicks were assumed to have fledged (Lewis 1929, Mendall 1936). Following fledging, chicks were assumed to feed at the adult rate and have similar metabolic requirements. Weekly colony food intake was estimated by multiplying the number of individuals feeding at the adult rate for that week by the daily food requirement derived from the microclimate and endotherm models. The total biomass of each prey species consumed for that week was calculated as the product of weekly consumption and proportional representation of prey species identified in stomach content analyses of birds collected during the corresponding week. The number of each prey species consumed was calculated by dividing the weekly consumed biomass of a given prey species by the mean weight of individuals identified in that week's stomach content analyses. To better investigate cormorant consumption of Yellow Perch in relation to perch population dynamics, Yellow Perch were further subdivided into size-classes so that the proportion of each size class in the cormorant diet could be examined. Because measures of percent frequency occurrence in stomachs, percent numerical occurrence, and percent biomass of a prey species can lead to differing inferences regarding cormorant diet, the importance of each prey species in cormorant diet was estimated using the relative importance index derived for cormorants by Fenech *et al* (2004) from the equations of George and Hadley (1979). Relative importance of a prey species is estimated by first calculating an absolute importance index for each species (from Fenech *et al.* 2004)

AI_a = % frequency of occurrence of prey taxon a + % by number of prey taxon a + % by mass of prey taxon a

The relative importance of prey item a, (RI_a), is then calculated:

$$RI_a = 100 \bullet AI_a / \sum_{p=1}^{n} AI_p$$

where AI_p is the absolute importance of prey taxon p in the diet and n is the number of different prey taxa in the diet. The resulting sum of the relative importance for all prey items in the diet is 100. Difference in the percent consumption of the four prey species of highest relative importance for each year was tested by breeding period using a one-way analysis of variance. The Bonferroni post-hoc test was used to examine differences between periods, and Levene's test for equality of variances was used to test the assumption of homoscedasticity.

Impacts on the Yellow Perch Population

The estimated number of Yellow Perch removed from southern Green Bay by cormorants was compared to the number of age-1 perch present in the bay in 2004 and age-2 perch present in 2005 estimated from a DNR perch statistical catch at age (SCAA) model (J. Netto, unpubl. model). Previous analysis examining density-dependent effects in the Yellow Perch population indicated that a highly variable linear relationship can predict age-1 abundance from young-of-the-year (YOY) catch per unit effort (CPUE) in the trawl at low to moderate levels. However, at high levels, survival from YOY to age-1 is reduced due to density dependent mechanisms (J. Netto unpubl. data). The 2003 cohort represents the only year-class in nearly two decades large enough to encounter the predicted density-dependent mechanisms.

Density-dependent effects and associated estimates of subadult (YOY through age-2) Yellow Perch abundance were investigated by examining the patterns in the relationship between estimates of the YOY index of abundance, estimates of age-1 Yellow Perch in the trawl data, and estimates of age-1 Yellow Perch from SCAA analysis (J. Netto, unpubl. data). Two estimates of Yellow Perch abundance were generated. The high estimate ignored density dependence and projected abundance based on a linear relationship. This is equivalent to assuming that the increased mortality from high Yellow Perch density occurs during and/or after the Yellow Perch become available to cormorant predation at age-1. The low estimate was calculated based on a stock recruitment relationship that included a density dependent term. This model did not fit as well as the linear representation, but may be more applicable to the current state. This model assumed that density dependent effects take place prior to the cormorant nesting season and therefore produces a low estimate of subadult Yellow Perch abundance at the beginning of the cormorant breeding season.

RESULTS

Reproductive Success

A high proportion of birds collected in southern Green Bay had prey present in their stomachs; 66% of stomachs contained prey items in 2004, and 83% of stomachs contained prey in 2005. In 2004, 1974 cormorant nests were counted on Cat Island; 2113 nests were counted in 2005. In 2005, cormorant nests on Cat Island had a 72% probability of remaining successful from the initial recording of the clutch through 21 d and a 56% probability that a single egg would produce a chick surviving to 21 d. Clutch size measures of central tendency in 2005 were similar with a mode and mean of 4.0 and 3.9 eggs per clutch, respectively. The associated modal number of chicks per clutch surviving to 21 d was 3.0, whereas the mean number of chicks per clutch surviving this period was 2.0.

Foraging Distribution

The density of cormorants nesting and loafing on Cat Island was too compact to allow counts of individual birds. During both years, there was no apparent temporal change in spatial distribution of foraging flocks. Three aerial surveys conducted on May 5, May 26, and August 20, 2004 observed 1203, 844, and 3178 cormorants in flying flocks or actively foraging within the study area (Figure 3). Three aerial surveys conducted on June 1, June 27, and August 15, 2005 observed 86, 745, and 4851 foraging cormorants, respectively (Figure 4). In both years 38% of foraging groups were observed within 10 km of Cat Island and 67%

were observed within 20 km of the breeding colony (Figure 3, Figure 4). In both years, each foraging location recorded within a 20 km radius of Cat Island was ≤ 4 km from at least one other recorded location within that area (Figure 3, Figure 4) Beyond the 20 km radius, foraging locations exhibited a wider spatial distribution, with most locations occurring within ≤ 10 km of another recorded location (Figure 3, Figure 4).

Cormorant Diet Composition

A total of 18 fish species encompassing 13 families were found in the stomach contents of cormorants removed from southern Green Bay (Table 1). No invertebrate species were identified. White Suckers (*Catostomus commersoni*), Yellow Perch, Walleye (*Stizostedion vitreum*), and Gizzard Shad (*Dorosoma cepedianium*) composed the greatest proportion of biomass by weight consumed by cormorants in both 2004 and 2005, although the relative proportions of each prey item in the diet differed between years (Table 2, Table 3). The most numerically abundant prey items in cormorant diet in 2004 were, in order of abundance, Yellow Perch, Gizzard Shad, Round Goby (*Dorosoma cepedianum*), and Spottail Shiner (*Notropis hudsonius*, Table 2). In contrast, the most numerically abundant prey items in 2005 were, in order of numerical abundance, Gizzard Shad, Round Goby, Yellow Perch, and Trout Perch (*Percopsis omiscomaycus*, Table 3). In decreasing order, the prey species with the highest relative importance indices in 2004 were Yellow Perch, Gizzard Shad, White Sucker, Spottail Shiner (*Notropis hudsonius*), and Round Goby, which had a combined index of 76 (Table 2). In 2005, prey species of importance were very similar, but the hierarchy of importance shifted to Gizzard Shad, White Sucker, Yellow Perch, and Round Goby, producing a combined index of 72 (Table 3). In 2004, excluding two fish removed from stomachs during the chick rearing period, Gizzard Shad were consumed exclusively during the chick independence period, so no statistical analyses were run for this species. There was no significant difference in consumption of Round Gobies ($F_{2,21}$ = 1.29, P = 0.303), White Suckers (($F_{2,21}$ = 0.41, P = 0.747), and Yellow Perch (($F_{2,21}$ = 1.80, P = 0.177, Figure 5) by breeding period in 2004. In 2005, however, Yellow Perch decreased significantly in the cormorant diet ($F_{2,18}$ = 10.63, P < 0.001), as did White Suckers ($F_{2,18}$ = 4.94, P = 0.01) as the season progressed; consumption of Round Gobies differed significantly during the chick rearing and chick independence periods ($F_{2,18}$ = 5.20, P = 0.009, Figure 6). Again, consumption of Gizzard Shad was confined primarily to the chick rearing period in 2005, and thus no species-specific analyses were performed.

Colony Consumption

Values are presented on a wwt. basis. The Micro2006b and Endo2006 models estimated a mean daily food requirement of a single adult cormorant using GISHFP to be 378 g/bird/d during the arrival period, 822 g/bird/d during incubation, 621 g/bird/d during chick rearing, and 243 g/bird/d during chick independence (Table 4). In contrast, when models used YPERFP values, mean daily food requirement was estimated as 611 g/bird/d during arrival, 1329 g/bird/d during incubation, 996 g/bird/d during chick rearing, and 393 g/bird/d during chick independence (Table 4). The associated estimate of fish consumption by the Cat Island population of cormorants ranged from ~ 0.38 and ~ 0.61 million kg of fish in both 2004 as estimated using GISHFP and YPERFP input values, respectively (Table 5). In 2005, the respective range for both input values was ~0.37 to ~ 0.57 million kg (Table 6). In 2004 the GISFP-derived lower estimate of numerical consumption of prey was ~ 30.1 million fish, while the higher YPERFP-derived estimate was ~ 44.8 million fish (Table 7). The number of fish consumed in 2005 ranged from ~ 18.4 to ~ 27.5 million fish using GISFP and YPERFP input values, respectively (Table 8). The models estimated that the Cat Island colony of cormorants consumed 55% to 60% more Yellow Perch by biomass and ~ 530% to 550% more by number in 2004 than in 2005; size class 70-79 mm was most prevalent in 2004, and size class 120-129 mm was most prevalent in 2005 (Figure 7). Scale samples indicated that the modal age (yr) of Yellow Perch consumed in 2004 was 1, whereas the modal age of Yellow Perch consumed in 2005 was 2. Thus, the 2003 Yellow Perch cohort was the age-class with highest representation the cormorant diet.

Consumption of Yellow Perch

A comparison of the perch abundance estimate assuming that density dependent mechanisms primarily impacted the 2003 Yellow Perch cohort prior to the cormorant breeding season and the GISHFP and YPERFP-derived consumption calculations suggested that cormorants consumed 33-50% of age-1 perch in 2004 and 11-17% of age-2 perch in 2005 (Figure 8). A comparison of the Yellow Perch abundance estimate assuming no density dependence and the GISHFP and YPERFP-derived consumption calculations suggested that cormorants consumed 15-24% of the age-1 fish in 2004 and 5-8% of the age-2 fish in 2005 (Figure 9).

DISCUSSION

Reproduction and Foraging Distribution

All reproductive parameters measured in 2005 were similar to those described by Custer *et al.* (1999) for Cat Island cormorants in 1994 and 1995. In addition, clutch size was similar to that observed in cormorants nesting in Maine (Mitchell, 1977) and Ontario (Peck and James 1983), and brood success was similar to that predicted by Postupalsky (1978) for Great Lakes cormorant populations.

Custer and Bunck (1992) observed that cormorants breeding on Cat Island tend to forage within 2 km of the breeding colony. The recorded locations of foraging cormorants in our study were not consistent with this observation. Further, flocks consisting of several-hundred cormorants were regularly observed flying past the collection location at Longtail Point, which is 2.5 km north of Cat Island. While the cormorants observed during aerial surveys in our study cannot be directly linked to Cat Island, the observed numbers of cormorants passing Longtail Point suggests that a large proportion of the colony regularly foraged further than 2 km from the breeding colony. More cormorants were recorded in August surveys compared to surveys conducted during other months. This increase is likely attributable to the addition of fledged chicks to foraging flocks. There was an apparent spatial delineation between flocks observed foraging within a 20 km radius of Cat Island and flocks foraging beyond this region. Palmer (1962) indicated that cormorants require a reliable food supply within 8-16 km of colonies or roosting locations. The observed spatial delineation might thus be indicative that birds observed north of the 20 km radius were not affiliated with the Cat Island breeding colony. The presence of nonbreeding cormorants in Green Bay is seemingly ephemeral, and when present, the number of individuals is difficult to ascertain due to an apparent lack of roosting site fidelity (pers. obs., K. Stromborg, pers. comm.). At present, the food habits of these individuals remains unknown.

Colony Consumption

The number of families and included fish consumed by cormorants in this study is lower than those of other studies conducted elsewhere in the Great Lakes (Diana *et al.* 1997, Neumann *et al.* 1997) as well as in the closed system of Lake Oneida, New York (Rudstam *et al.* 2004). However, regurgitant of nestling cormorants on Green Bay islands of northern

Lake Michigan contained fewer prey species than regurgitant elsewhere on northern Lake Michigan, Lake Huron, Georgian Bay, and Lake Superior (Ludwig *et al.* 1989), suggesting that our findings are not atypical for Green Bay.

Our estimates of daily food requirement of a single adult cormorant are similar to previous estimates of cormorant food requirements. Dunn (1975) estimated breeding adult cormorants consume between 20-25% of their body mass/d, equivalent to a range of 400-500 g/bird/d for Cat Island cormorants. Similarly, Glahn and Brugger (1995) estimated a mean daily food intake of approximately 22% of adult body mass/d, and Weseloh and Casselman (1992) estimated a daily intake of 25% of body mass. Estimates derived using GISHFP input values more often fell within the range of prior estimates than did those calculated using YPERFP, indicating that GISFP values might better reflect daily food requirement

Total consumption of fish biomass by the Cat Island colony is comparable to existing estimates for other Great Lakes colonies. Johnson *et al.* (2002) estimated that a Lake Ontario cormorant colony with a mean annual nest count of ~6000 consumed an average of 1.4 million kg, comprised of ~ 32.8 million fish, proportional to Cat Island data. However, all but the 2005 GISHFP-derived estimate of numerical fish consumption by Cat Island cormorants exceeded the estimate of Johnson *et al.* (2002). This is likely due to differences in total length and weight of prey species. The appearance of the large 2003 Yellow Perch cohort augmented by high Gizzard Shad production in 2004 and 2005 resulted in a profusion of small-bodied fish in southern Green Bay. In order to meet daily energy demands, Cat Island cormorants had to consume a greater number of fish relative to birds in systems where larger fish predominate.

Depredation of the Southern Green Bay Yellow Perch Fishery

Combined sport and commercial harvest of Yellow Perch was 18,269 kg representing 131,053 individual perch in 2004 and 39,124 kg representing 356,820 individual perch in 2005 (WDNR data), which is markedly lower than estimates of cormorant consumption of Yellow Perch in terms of both total number and biomass. Size-class and scale sample data of most perch consumed by cormorants in both years were consistent with the 2003 cohort. Female Yellow Perch in Southern Lake Michigan typically reach maturity in their third year, after which they produce more eggs annually as they age (Wells and Jorgensen 1983). The majority of Yellow Perch consumed by cormorants were accordingly non-reproducing individuals, with the remaining perch consisting of size classes associated with lower reproductive output (Wells 1983). While cormorants may represent a high source of mortality to age-1 and older Yellow Perch in southern Green Bay, mortality of YOY perch resulting from other sources may contribute to reduced recruitment. A previous decline in the Yellow Perch population of southern Green Bay in the 1960s was attributed to the then rapidly increasing Alewife (*Alosa pseudoharengus*) population (Wells 1977), which served as a dual source of predation and competition to perch. However, Alewife abundance was low during the decline in perch recruitment that occurred throughout 1990s, and no single factor has yet been linked to the failing perch population (Madenjian *et al.* 2002). Research elsewhere in Lake Michigan has attributed impaired recruitment of Yellow Perch to competition and predation from other fish species, such as White Perch, as well as cannibalistic predation of YOY Yellow Perch (Shroyer and McComish 2000, Fulford *et al.* 2006). Few YOY perch were identified in the stomach contents of cormorants in this study, indicating cormorants are likely not a large source of larval perch mortality.

Mortality of subadult year classes is characteristically higher than that of older classes for a number of fish species (Houde 1987, Houde 1989). Consequently, the number of subadult Yellow Perch consumed by cormorants cannot be directly equated to adults. Our data suggest that the impact of cormorants on the Yellow Perch population is not manifested in consumption of breeding stock or the larval population, but rather in removal of adult equivalents, or young perch that would eventually make a reproductive contribution to the population. Burnett *et al.* (2002) found that in the presence of an increasing cormorant population on the eastern basin of Lake Ontario, the abundance of Yellow Perch remained low, despite the consistent production of large year classes. This indicated that cormorant predation of subadult perch had a measurable effect on the adult population (Burnett *et al.* 2002). Similarly, Rudstam *et al.* (2004) estimated that Yellow Perch and Walleye (*Stizostedion vitreum*) collectively represented 57-77% of cormorant diet on Lake Oneida, New York, and suggested that this consumption represented 9-121% of subadult Yellow Perch expected to be recruited to the adult population. These data were indicative that a prior decline in the Oneida Lake adult Yellow Perch population was likely attributable to cormorant consumption of subadult perch (Rudstem *et al.* 2004).

The rebound in the southern Green Bay Yellow Perch population occurred after the local breeding cormorant population had remained stable at ~2000 breeding pairs for 7 years, indicating that cormorants were not the primary factor limiting the Yellow Perch population. However, the estimated number of Yellow Perch consumed in this study suggests that the impact of cormorant consumption on the southern Green Bay perch population is not negligible. At high levels of YOY to age-1 Yellow Perch abundance, mortality is compensatory at some level. However, if cormorant predation of Yellow Perch becomes additive, the consumption of large numbers of subadults will slow recovery of the perch population. When considering cormorant impacts on the southern Green Bay Yellow Perch fishery or perch spawning stock biomass accumulation, any component of additive mortality would limit survival and therefore population growth. The consumption of 15-24% of age-1 Yellow Perch in 2004 is likely too large a proportion of the perch population to be overcome by compensatory mechanisms.

When addressing the Cat Island cormorant population as a potential threat to the southern Green Bay Yellow Perch fishery, the limitations and assumptions of colony consumption warrant consideration. There is potential for bias in estimating the proportion each prey item represented in cormorant diet associated with the extrapolation of prey species composition for a single sample day to the entire week. Because colony consumption was calculated as the product of the Cat Island population and proportional representation of prey items in the daily food budget of a single cormorant, there is potential to further over- or underestimate the removal of a given species by cormorants from the southern Green Bay system. While our energetic and daily food intake estimates are characteristic of cormorant requirements, the potential for error in the consumption estimates of biomass and number of a prey species must be acknowledged, and inferences regarding management of both cormorants and fisheries should be approached cautiously.

The temporal distribution of density dependent mechanisms impacting the Yellow Perch population is unknown. Therefore, the degree to which density dependence affects abundance of age-1 yellow perch prior to the period they are susceptible to cormorant predation is difficult to estimate. Trawl data indicated a substantial drop in the strength of the 2003 cohort between the trawl sampling at YOY and age-1 in August (DNR data). If the majority of the increased mortality was enacted prior to spring of the year after hatching (i.e. over winter survival), then the population of Yellow Perch available to the cormorants would have been lower than that predicted from the high estimate of perch vulnerable to cormorant predation. If density dependent mechanisms continued to be significant during and after the cormorant nesting period, then our estimates of mortality based on the low estimate of perch vulnerable to predation may overstate the impact on the Yellow Perch population.

Other Important Prey Items

Cormorants are opportunistic foragers (Bur *et al.* 1997, Diana *et al.* 1997, Ross and Johnson 1997, Rudstam *et al.* 2004). However, Alewives, which have a relatively high energy content, are seemingly preferred prey of cormorants throughout the Great Lakes (Weseloh *et al.* 1995), and have been suggested as the pivotal factor affecting cormorant reproductive output, fledgling condition and post-fledging survival of cormorants on Lake Ontario (Weseloh and Ewins 1994). Ludwig *et al.* (1989) found that in late summer the Alewife component of cormorant regurgitate approached 100% in colonies on Lakes Huron, Michigan, and Superior, but hypothesized that cormorants are readily able to shift to secondary prey following a decline in Alewife availability. Ludwig and Summer (1997) proposed that the presence of Alewives as alternate prey might buffer consumption of Yellow Perch. Additionally, Maruca (1997) noted that cormorant predation of Alewives might reduce competition with Yellow Perch as well as predation of perch larvae by Alewives. Of fish identified in regurgitate of southern Green Bay cormorant chicks in 1983, Alewives comprised 72% of identifiable prey items (B. Belonger unpubl. data). By 1999, this proportion was 22% (T. Erdman unpubl. data), a drop attributable to a decline in Green Bay-Lake Michigan Alewife populations (Madenjian *et al.* 2002). While Alewives composed very little of Cat Island cormorant diets in 2004 and 2005, Gizzard Shad, another Cluepid, was identified as one of the most important components of cormorant diet. Gizzard Shad have also been associated with preferential consumption by cormorants (Fenech *et al.* 2004). Therefore, the gross disparity in prey composition across breeding seasons in southern Green Bay is most likely indicative of a dietary shift to Gizzard Shad in the absence of Alewives. Providing Gizzard Shad have in part assumed the ecological role previously associated with Alewives, this species might be acting as a dietary buffer, thereby alleviating consumption pressure on Yellow Perch.

White Suckers and Round Gobies also ranked high on relative importance indices in both years. The removal of Round Gobies from the ecosystem may be of benefit to a number of fish species. The Round Goby, an invasive exotic, is a relatively new arrival to the Great Lakes (Jude *et al.* 1992). Laboratory experiments have shown Round Gobies readily consume Lake Trout (*Salvelinus namaycush*) eggs and fry (Chotkowski and Marsden 1999), and are capable of consuming all offspring from Smallmouth Bass (*Micropterus dolomieu*) nests in ~ 15 min when a guardian male is absent (Steinhart *et al.* 2004). Round Gobies have previously been linked to recruitment failure of Mottled Sculpin (*Cottus bairdi*) in Southern Lake Michigan (Janssen and Jude 2001), and may therefore be affecting other species throughout the lake. The effectiveness of White Suckers to exploit benthic prey, reduces the number of prey available to perch, thereby suppressing perch growth, reducing quality of body composition, and affecting reproductive output (Johnson 1977, Hayes *et al.* 1992, Hayes and Taylor 1994). Our findings emphasize the need to address the role of cormorants in relation to the entire southern Green Bay food web, allowing a more informed foundation upon which to base management decisions.

Management Implications

In an effort to reduce total colony food intake on Cat Island as well as other cormorant colonies in Green Bay, oiling of cormorant eggs is scheduled for the 2006 breeding season. To further refine estimates regarding cormorant depredation of the southern Green Bay Yellow Perch population and better assess the effectiveness of management actions, consumption of the 2003 cohort should continue to be monitored as perch reach maturity. This will then enable the extrapolation of adult equivalents consumed during 2004 and 2005. Only then will an accurate representation of population-wide impacts of cormorant consumption of Yellow Perch in southern Green Bay be possible. Further, these analyses will better indicate whether this consumption is either additive or compensatory.

Although the population of cormorants breeding in southern Green Bay seems to have reached a plateau, the northern Green Bay cormorant population has continued to increase over the last several years (S. Matteson pers. comm. While the Yellow Perch fishery of concern in the present study does not extend into northern Green Bay, the increasing cormorant population in this area has begun to raise concerns regarding impacts on other fish resources. A large degree of heterogeneity, including differences in bathymetry and habitat type, can exist between different systems (Neuman *et al.* 1997). When assessing the impact of cormorant predation on fisheries, site specificity is of great importance, and the findings of this study should not be extrapolated to include cormorant and fish populations of upper Green Bay or Lake Michigan. However, the modeling approach used in this study does allow calculation of spatially- and temporally-explicit estimates of energy requirements. If food habits data were available for other locations throughout Green Bay, the metabolic requirements and associated food intake for local cormorants might be used to estimate the biomass and number of fish consumed across the landscape.

The dramatic increase in Great Lakes cormorant populations has been ascribed to a number of factors including reduced levels of organochlorine contaminants in the environment, reduced human persecution, and increased availability of forage fish (Weseloh and Ewins 1994). In addition, rapid growth of the Mississippi catfish industry in the 1980s introduced a food base that may increase overwinter survival of cormorants (Weseloh and Ewins 1994, Glahn *et al.* 1997). Due to real and perceived damage to public resources in the northern breeding (Ludwig *et al.* 1989, Burnett *et al.* 2002, Johnson *et al.* 2002,) and southern wintering (Glahn and Brugger 1995, Glahn *et al.* 1998, Fenech *et al.* 2004) areas of cormorant migratory range, control efforts have been initiated in a number of states including Michigan, Minnesota and Mississippi under a federal public resource depredation order (PRDO). As cormorant populations are currently managed at both extremes of their spatiotemporal distribution, an approach integrating management across the flyway is required to assess and ensure the success of management plans throughout cormorant range. Future studies might seek to coordinate research between wintering regions in the southern United States and breeding colonies in the northern United States and Canada. As North American cormorant populations increase, elucidating factors that regulate migratory populations of cormorants, particularly factors that increase overwinter survival and reproductive output, is imperative if populations are to be subject to management efforts. Spatially explicit modeling of cormorant energy demands might be of further value in calculating the requirements of migrating cormorants as well as cormorants wintering in the Southern United States. This would allow the most comprehensive approach to assessing impacts to public resources on an annual, population-wide scale, leading to improved management of cormorants throughout their range.

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Table 1. Prey species identified in stomachs of Double-crested Cormorants nesting on Cat Island, southern Green Bay, WI in 2004 and 2005.

Family	Common Name	Scientific Name
Catostomidae		
	White Sucker	*Catostomus commersoni*
Clupeidae		
	Alewife	*Alosa pseudoharengus*
	Gizzard Shad	*Dorosoma cepedianum*
Cyprinidae		
	Common Carp	*Cyprinus carpio*
	Spottail Shiner	*Notropis hudsonius*
Cyprinodontidae		
	Banded Killifish	*Fundulus diaphanus*
Esocidae		
	Northern Pike	*Esox lucius*
Gasterosteidae		
	Nine-spine Stickleback	*Pungitius pungitius*
Gobiidae		
	Round Goby	*Neogobius melanostomus*
Ictaluridae		
	Channel Catfish	*Ictalurus punctatus*
Osmeridae		
	Rainbow Smelt	*Osmerus mordax*
Percicthyidae		
	White Bass	*Morone chrysops*
	White Perch	*Morane americana*
Percidae		
	Logperch	*Percina caprodes*
	Walleye	*Stizostedion vitreum*
	Yellow Perch	*Perca flavescens*
Percopsidae		
	Trout Perch	*Percopsis omiscomaycus*
Sciaenidae		
	Freshwater Drum	*Aplodinotus grunniens*

Table 2. Number, biomass and relative importance indices of prey species found in stomachs of Double-crested Cormorants collected from Southern Green Bay, WI from May 19 to September 30, 2004.

				Individual Fish Weight (g)				
Species	N	% Number	% Frequency of Occurrence	Mean	SE	Total Weight (kg)	% Weight	Relative Importance
Alewife	232	4.92	10.73	18.43	0.98	4.27	6.89	6
Banded Killifish	4	0.08	0.35	2.22	0.27	0.01	0.02	0
Channel Catfish	2	0.00	0.35	97.66	13.26	0.20	0.00	0
Common Carp	0	0.00	0.00	0.00	0.00	0.00	0.00	0
Freshwater Drum	18	0.38	4.84	57.63	15.78	0.66	1.07	2
Gizzard Shad	1348	28.61	25.26	3.31	0.14	4.41	7.11	15
Logperch	1	0.02	0.35	1.94	0.00	0.00	0.00	0
Nine Spine Stickleback	1	0.02	0.35	1.80	0.00	0.00	0.00	0
Northern Pike	6	0.13	1.38	59.82	17.17	0.36	0.58	1
Round Goby	545	11.57	20.07	12.96	0.47	4.15	6.69	10
Smelt	0	0.00	0.00	0.00	0.00	0.00	0.00	0
Spottail Shiner	524	11.12	25.26	5.97	0.14	3.12	5.03	10
Trout Perch	49	1.04	3.81	7.18	0.65	0.35	0.57	1
Walleye	64	1.36	15.92	125.54	12.52	7.55	12.17	7
White Bass	38	0.81	7.96	9.66	1.79	0.31	0.50	2
White Perch	64	1.36	13.49	18.36	10.05	1.18	1.89	4
White Sucker	73	1.55	23.53	366.82	17.45	24.93	40.16	16
Yellow Perch	1743	36.99	43.60	6.23	0.53	10.56	17.01	25
Total	4712	100	-	-	-	62.08	100	100

Table 3. Number, biomass and relative importance indices of prey species found in stomachs of Double-crested Cormorants collected from Southern Green Bay, WI from April 28 to September 21, 2005.

				Individual Fish Weight (g)				
Species	N	% Number	% Frequency of Occurrence	Mean	SE	Total Weight (kg)	% Weight	Relative Importance
Alewife	121	2.74	6.67	32.39	0.79	3.92	3.60	3
Banded Killifish	0	0.00	0.00	0.00	0.00	0.00	0.00	0
Channel Catfish	1	0.02	0.22	4.00	0.00	0.00	0.00	0
Common Carp	16	0.36	1.11	16.80	2.67	0.27	0.25	0
Freshwater Drum	88	2.00	6.45	74.96	35.68	6.60	6.06	4
Gizzard Shad	2327	52.78	35.79	10.72	2.15	24.94	22.91	29
Logperch	0	0.00	0.00	0.00	0.00	0.00	0.00	0
Nine Spine Stickleback	0	0.00	0.00	0.00	0.00	0.00	0.00	0
Northern Pike	2	0.05	0.44	221.81	113.84	0.44	0.41	0
Round Goby	589	13.36	15.78	10.63	0.34	5.71	5.24	9
Smelt	5	0.11	0.89	6.75	2.06	0.01	0.01	0
Spottail Shiner	233	5.28	13.78	9.01	0.31	2.10	1.93	5
Trout Perch	307	6.96	14.01	12.27	0.33	3.77	3.46	6
Walleye	36	0.82	8.00	244.77	19.87	8.81	8.10	5
White Bass	9	0.20	0.67	18.10	11.48	0.13	0.12	0
White Perch	60	1.36	9.34	23.65	4.31	1.85	1.70	3
White Sucker	180	4.08	33.12	198.83	36.32	39.97	36.72	20
Yellow Perch	435	9.87	32.24	21.82	1.53	10.34	9.49	14
Total	4409	100	-	-	-	-	100	100

Table 4. Food requirement (g/wwt/bird/d) of an adult and hatch year Double-crested Cormorant on southern Green Bay, WI in 2004 and 2005 estimated by Micro2006b and Endo2006 with Yellow Perch (YPERFP) and Gizzard Shad (GISHFP) input values.

		Food Requirement (g wet weight/d)							
		2004				2005			
		GISHFP		YPERFP		GISHFP		YPERFP	
Sample Week	Julian day (2004/2005)	Adult	Hatch Year	Adult	Hatch Year	Adult	Hatch Year	Adult	Hatch Year
15 Apr - 21 Apr	109/108	335	-	542	-	298	-	482	-
22 Apr - 28 Apr	116/115	406	-	656	-	421	-	680	-
29 Apr - 6 May	123/122	390	-	631	-	418	-	676	-
7 May - 13 May	130/129	857	-	1386	-	879	-	1421	-
14 May - 20 May	137/136	864	-	1397	-	908	-	1468	-
21 May - 27 May	144/143	874	-	1413	-	751	-	1215	-
28 May - 2 Jun	151/105	786	-	1271	-	654	-	1057	-
3 Jun - 9 Jun	158/157	738	-	1194	-	571	-	924	-
10 Jun - 16 Jun	165/164	712	-	1152	-	554	-	896	-
17 Jun - 23 Jun	172/171	753	-	1218	-	617	-	997	-
24 Jun - 30 Jun	179/178	792	-	1280	-	509	-	824	-
1 Jul - 7 Jul	186/185	722	-	1168	-	646	-	1045	-
8 Jul - 14 Jul	193/192	615	-	995	-	531	-	858	-
15 Jul - 21 Jul	200/199	570	-	922	-	458	-	740	-
22 Jul - 28 Jul	207/206	601	-	972	-	540	-	873	-
29 Jul - 4 Aug	214/213	231	230	374	371	221	215	358	348
5 Aug - 11 Aug	221/220	291	289	471	467	215	214	348	347
12 Aug - 18 Aug	228/227	285	283	461	457	224	219	363	354
19 Aug - 25 Aug	235/234	290	288	469	465	232	230	375	372
26 Aug - 1 Sep	242/241	246	244	398	395	209	208	338	336
2 Sep - 8 Sep	249/248	250	248	404	401	230	224	371	362
9 Sep - 15 Sep	256/255	252	250	408	404	224	222	361	359

Table 5. Total biomass (kg) of prey species consumed by the entire colony of Double-crested Cormorants on Cat Island, southern Green Bay, WI in 2004 estimated by Micro2006b and Endo2006 with Yellow Perch (YPERFP) and Gizzard Shad (GISHFP) input values.

	Arrival		Incubation		Chick Rearing		Chick Independence		Total	
Prey Species	GISHFP	YPERFP	GISHFP	YPERFP	GISHFP	YPERFP	GISHFP	YPERFP	GISHFP	YPERFP
Alewife	0	0	217	351	17,255	27,900	6,096	8,663	23,568	36,914
Carp	0	0	0	0	0	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0	439	708	439	708
Freshwater Drum	406	656	1,199	1,938	299	484	3,876	6,037	5,780	9,115
Gizzard Shad	0	0	0	0	37	59	21,888	31,073	21,925	31,132
Killifish	0	0	0	0	9	14	12	20	21	34
Logperch	0	0	0	0	0	0	4	7	4	7
Nine Spine Stickleback	9	15	13	21	0	0	0	0	22	36
Northern Pike	0	0	0	0	22	36	4,128	4,830	4,150	4,866
Round Goby	477	772	2,005	3,242	23,720	38,353	11,390	18,376	37,593	60,744
Shiner Sp.	823	1,331	3,349	5,415	140	227	79	128	4,392	7,102
Smelt	0	0	0	0	0	0	0	0	0	0
Spottail Shiner	5,134	8,302	8,896	14,384	4,554	7,363	2,761	4,024	21,346	34,074
Trout Perch	0	0	0	0	0	0	0	0	0	0
Walleye	4,864	7,865	15,105	24,423	14,628	23,652	8,049	12,554	42,646	68,494
White Bass	105	170	363	586	239	386	999	1,507	1,706	2,649
White Perch	30	48	159	256	1,392	2,250	2,735	3,359	4,315	5,914
White Sucker	16,882	27,296	51,682	83,566	50,095	80,999	27,897	56,248	146,556	248,109
Yellow Perch	2,476	4,003	10,095	16,323	39,076	63,183	12,635	16,072	64,283	99,581
Total	31,207	50,458	93,083	150,506	151,467	244,907	102,989	163,606	378,745	609,478

Table 6. Total biomass (kg) of prey species consumed by the entire colony of Double-crested Cormorants on Cat Island, southern Green Bay, WI in 2005 estimated by Micro2006b and Endo2006 with Yellow Perch (YPERFP) and Gizzard Shad (GISHFP) input values.

	Arrival		Incubation		Chick Rearing		Chick Independence		Total	
Prey Species	GISHFP	YPERFP	GISHFP	YPERFP	GISHFP	YPERFP	GISHFP	YPERFP	GISHFP	YPERFP
Alewife	0	0	0	0	18,709	30,250	111	146	18,820	30,396
Carp	0	0	0	0	1,894	3,063	151	196	2,045	3,259
Channel Catfish	0	0	0	0	0	0	5	7	5	7
Freshwater Drum	0	0	0	0	1,783	2,882	9,715	12,759	11,498	15,641
Gizzard Shad	0	0	0	0	18,324	29,628	67,424	88,555	85,748	118,183
Killifish	0	0	0	0	0	0	0	0	0	0
Logperch	0	0	0	0	0	0	0	0	0	0
Nine Spine Stickleback	0	0	0	0	0	0	0	0	0	0
Northern Pike	1,168	1,889	0	0	0	0	0	0	1,168	1,889
Round Goby	72	117	2,050	3,314	13,447	21,742	470	617	16,038	25,790
Shiner Sp.	0	0	0	0	0	0	0	0	0	0
Smelt	0	0	0	0	40	65	11	14	51	80
Spottail Shiner	1,254	2,027	2,940	4,753	1,634	2,642	1,354	1,779	7,182	11,201
Trout Perch	2,050	3,314	6,687	10,812	2,187	3,537	92	121	11,016	17,783
Walleye	2,186	3,534	8,006	12,945	15,555	25,151	4,499	5,898	30,246	47,528
White Bass	0	0	203	329	9	15	103	136	316	479
White Perch	882	1,426	3,660	5,919	2,365	3,823	1,244	1,634	8,150	12,801
White Sucker	21,012	33,975	57,034	92,218	35,348	57,155	24,786	32,518	138,180	215,866
Yellow Perch	4,960	8,020	13,672	22,106	19,155	30,972	2,515	3,299	40,302	64,397
Total	33,584	54,302	94,252	152,396	130,449	210,924	112,480	147,678	370,765	565,300

Table 7. Total number (x 1000) of prey species consumed by the entire colony of Double-crested Cormorants on Cat Island, southern Green Bay, WI in 2004 estimated by Micro2006b and Endo2006 with Yellow Perch (YPERFP) and Gizzard Shad (GISHFP) input values.

	Arrival		Incubation		Chick Rearing		Chick Independence		Total	
Prey Species	GISHFP	YPERFP	GISHFP	YPERFP	GISHFP	YPERFP	GISHFP	YPERFP	GISHFP	YPERFP
Alewife	0	0	10	16	738	1,194	1,872	2,289	2,621	3,499
Carp	0	0	0	0	0	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0	9	14	9	14
Freshwater Drum	15	25	15	24	6	10	205	258	241	317
Gizzard Shad	0	0	0	0	3	5	6,158	8,376	6,161	8,381
Killfish	0	0	0	0	15	25	4	7	20	32
Logperch	0	0	0	0	0	0	2	4	2	4
Nine Spine Stickleback	15	25	7	12	0	0	0	0	23	37
Northern Pike	0	0	0	0	3	6	95	110	98	115
Round Goby	77	124	114	185	1,930	3,120	1,223	1,767	3,344	5,196
Shiner Sp.	141	227	508	822	19	30	4	7	672	1,087
Smelt	0	0	0	0	0	0	0	0	0	0
Spottail Shiner	628	1,015	1,101	1,781	1,669	2,698	812	1,191	4,209	6,685
Trout Perch	0	0	0	0	0	0	0	0	0	0
Walleye	54	87	191	308	111	180	91	133	447	708
White Bass	15	25	33	54	14	23	354	442	417	544
White Perch	15	25	27	43	17	28	531	648	591	745
White Sucker	40	64	125	203	158	256	135	222	458	745
Yellow Perch	373	604	1,474	2,384	7,014	11,341	1,924	2,322	10,786	16,651
Total	1,373	2,221	3,606	5,831	11,699	18,916	13,420	17,790	30,098	44,758

Table 8. Total number (x 1000) of prey species consumed by the entire colony of Double-crested Cormorants on Cat Island, southern Green Bay, WI in 2005 estimated by Micro2006b and Endo2006 with Yellow Perch (YPERFP) and Gizzard Shad (GISHFP) input values.

	Arrival		Incubation		Chick Rearing		Chick Independence		Total	
Prey Species	GISHFP	YPERFP	GISHFP	YPERFP	GISHFP	YPERFP	GISHFP	YPERFP	GISHFP	YPERFP
Alewife	0	0	0	0	586	948	4	5	590	953
Carp	0	0	0	0	129	208	3	4	132	212
Channel Catfish	0	0	0	0	0	0	1	2	1	2
Freshwater Drum	0	0	0	0	79	128	296	389	376	518
Gizzard Shad	0	0	0	0	4,628	7,482	6,498	8,539	11,126	16,022
Killfish	0	0	0	0	0	0	0	0	0	0
Logperch	0	0	0	0	0	0	0	0	0	0
Nine Spine Stickleback	0	0	0	0	0	0	0	0	0	0
Northern Pike	5	9	0	0	0	0	0	0	5	9
Round Goby	2	3	150	243	1,239	2,004	46	60	1,437	2,310
Shiner Sp.	0	0	0	0	0	0	0	0	0	0
Smelt	0	0	0	0	9	14	1	2	10	16
Spottail Shiner	123	198	244	394	178	287	229	301	773	1,181
Trout Perch	161	260	581	939	163	263	23	30	927	1,492
Walleye	8	12	32	52	62	100	23	30	124	194
White Bass	0	0	19	30	9	14	4	5	31	49
White Perch	8	13	76	123	87	141	102	134	274	412
White Sucker	51	82	237	383	217	351	128	168	633	984
Yellow Perch	229	370	638	1,031	898	1,452	205	270	1,969	3,122
Total	585	946	1,977	3,196	8,284	13,394	7,563	9,938	18,408	27,474

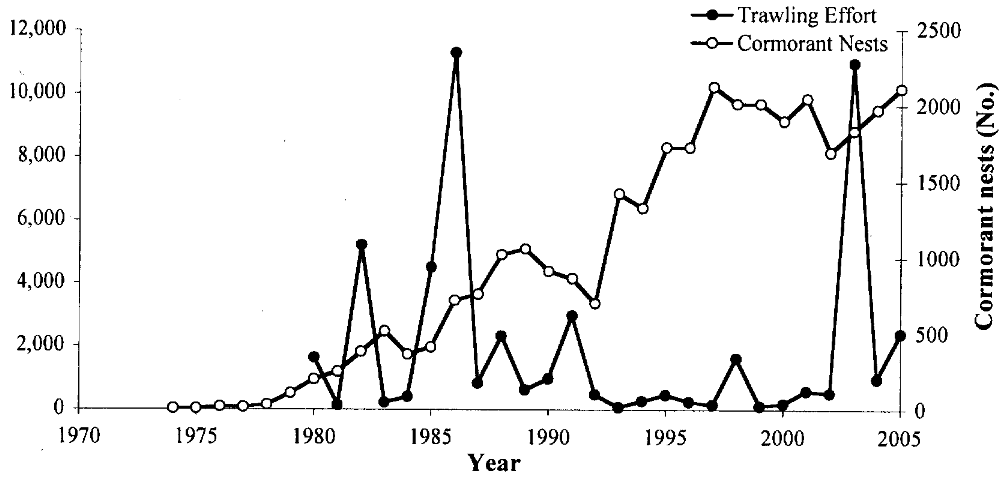

Figure 1. Number of Double-crested Cormorant nests on Cat Island (1974-2005) and annual average catch per trawl hour of young of the year (YOY) Yellow Perch at shallow sites trawling locations in southern Green Bay, WI.

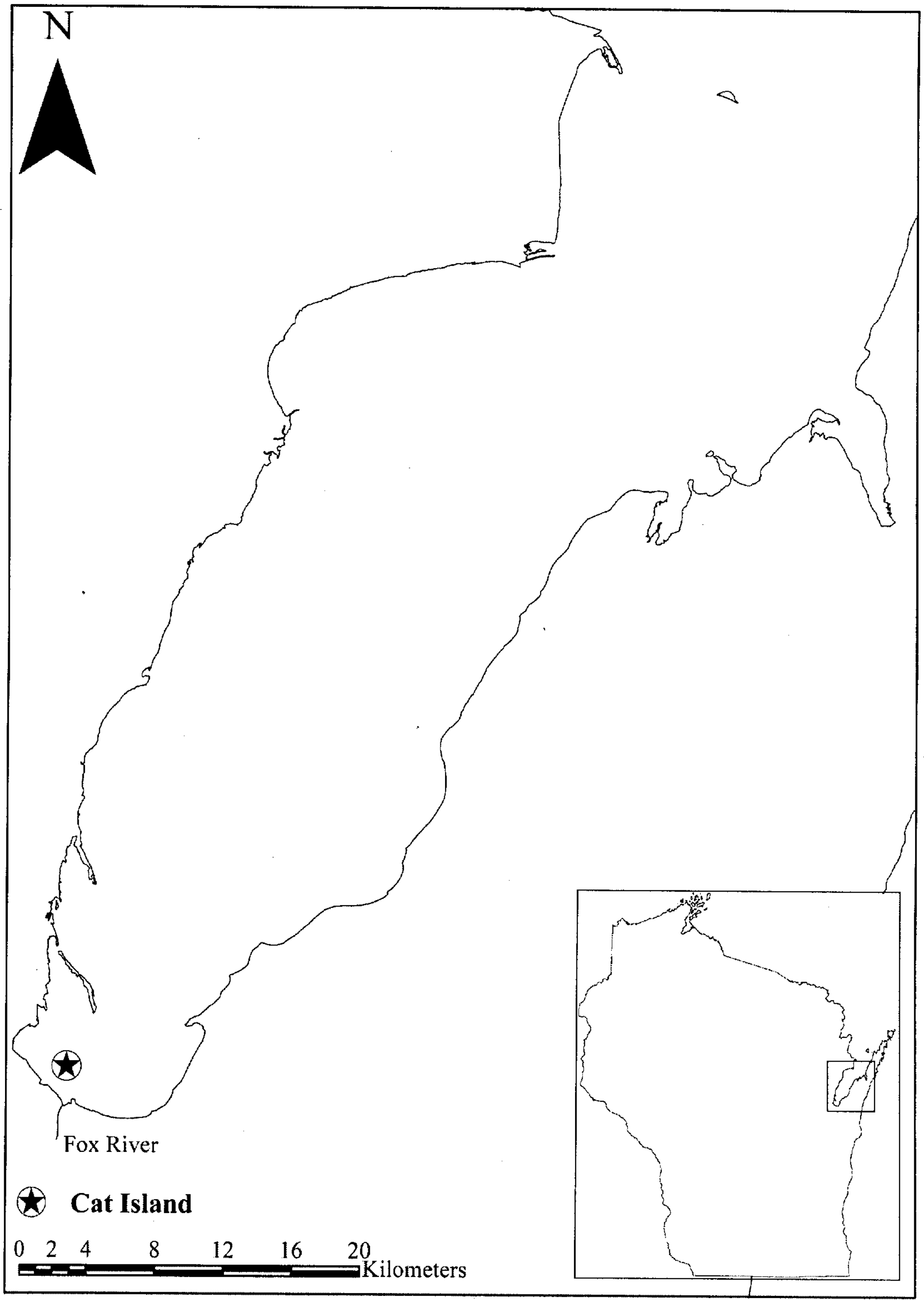

Figure 2. Map of study area.

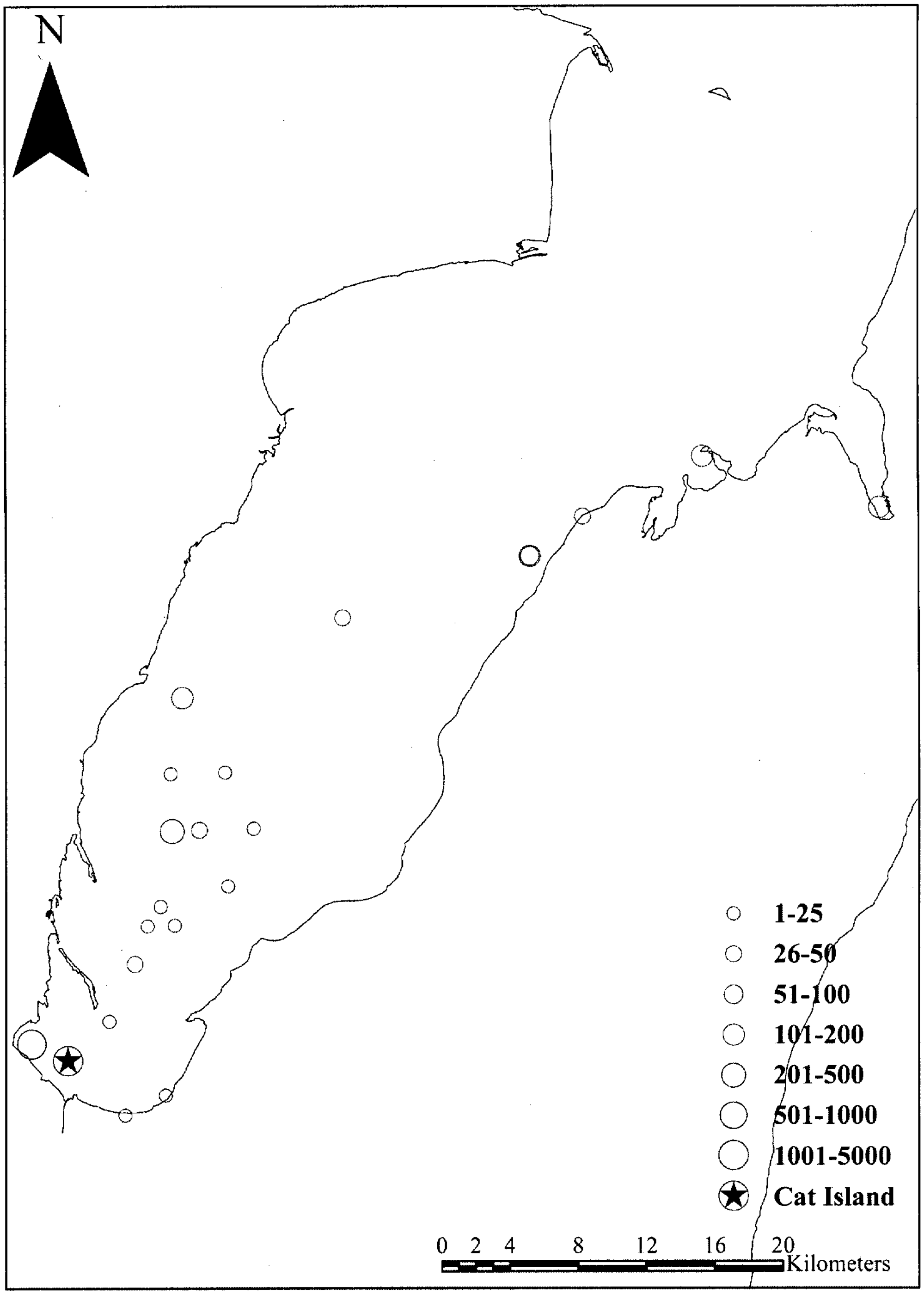

Figure 3. Approximate numbers and locations of Double-crested Cormorants observed during three aerial surveys conducted in southern Green Bay, WI in 2004.

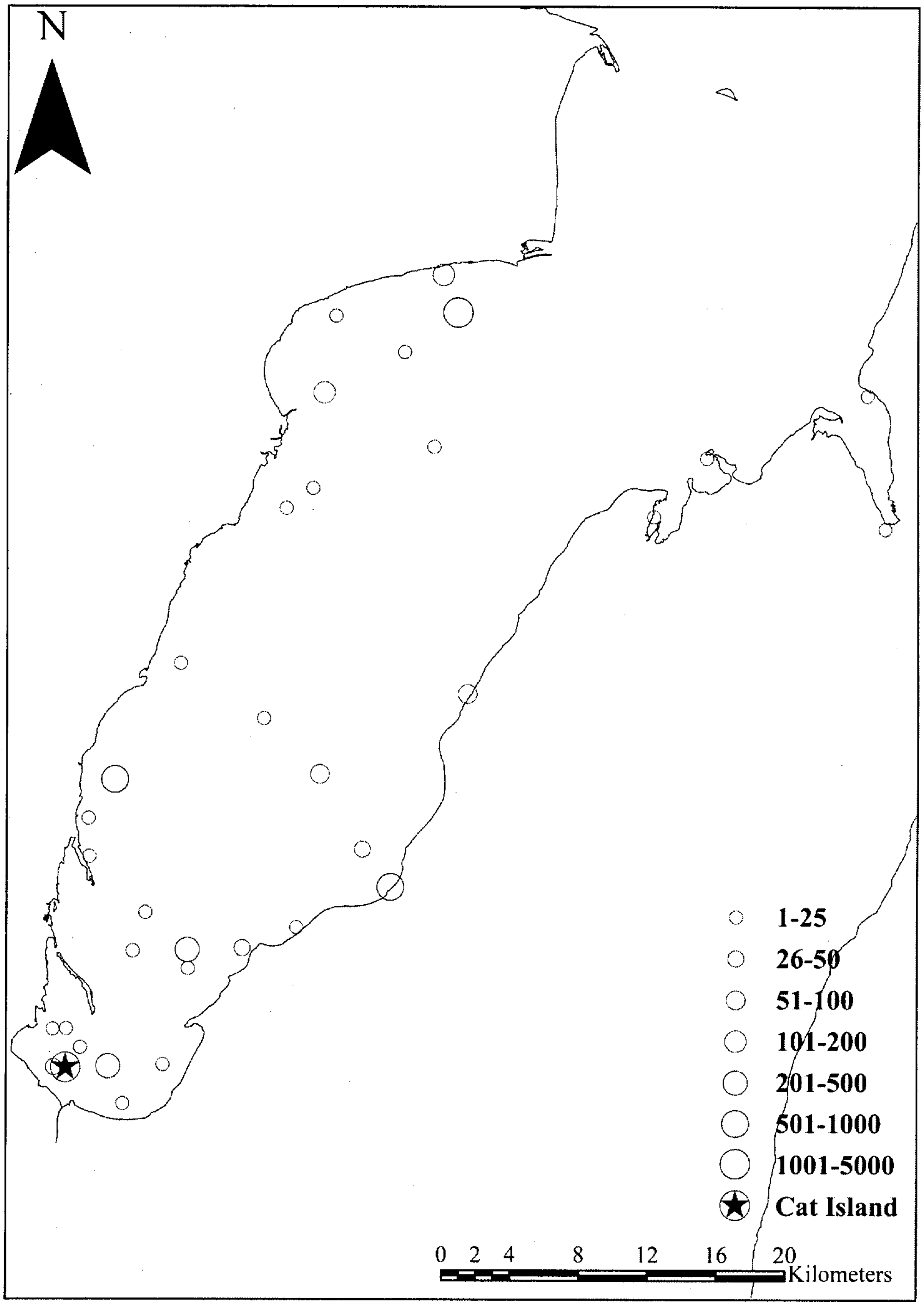

Figure 4. Approximate numbers and locations of Double-crested Cormorants observed during three aerial surveys conducted in southern Green Bay, WI in 2005.

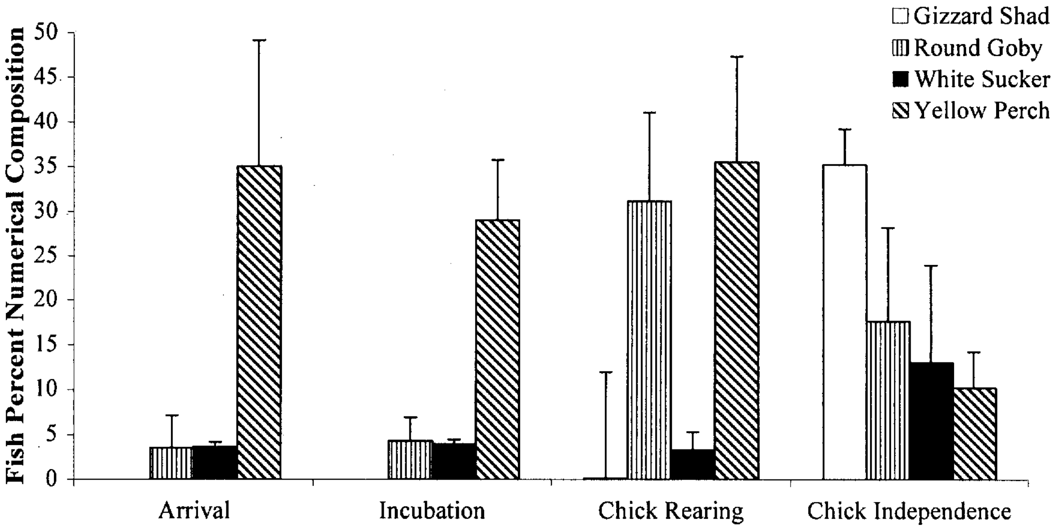

Figure 5. Percent of total diet represented by prey species of highest relative importance in the diets of Double-crested Cormorants nesting on Cat Island, southern Green Bay, WI during each period of the 2004 breeding season. Values are means with standard error bars.

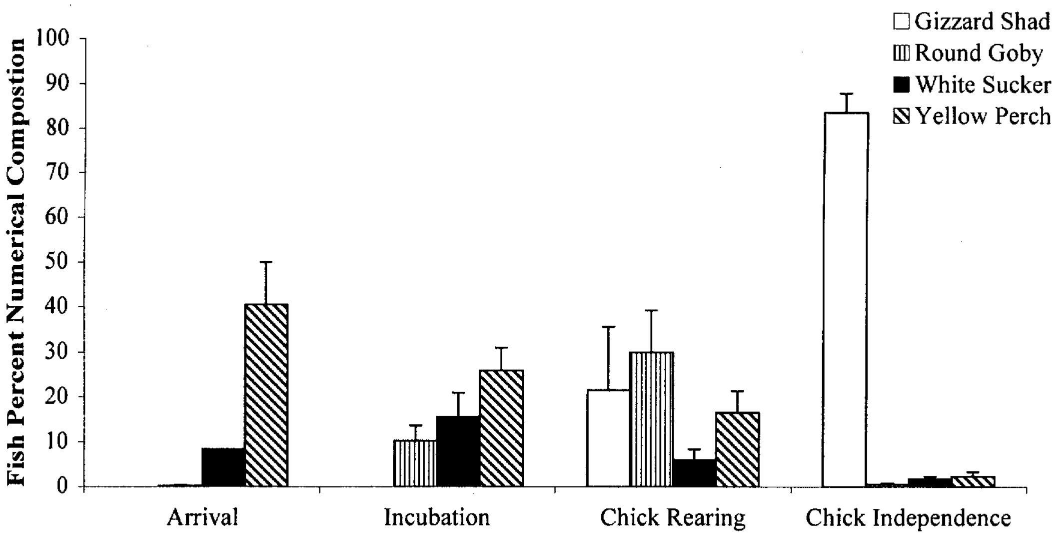

Figure 6. Percent of total diet represented by prey species of highest relative importance in the diets of Double-crested Cormorants nesting on Cat Island, southern Green Bay, WI during each period of the 2005 breeding season. Values are means with standard error bars.

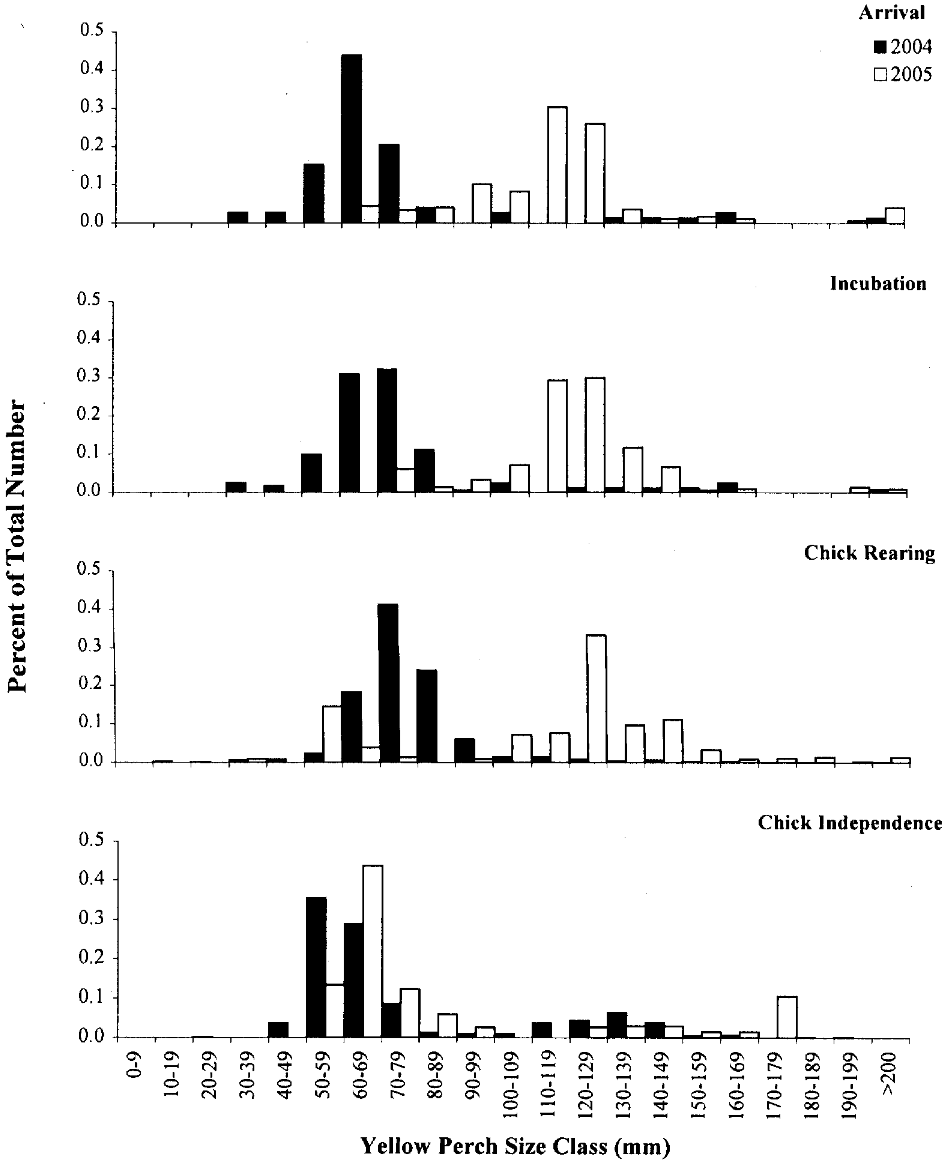

Figure 7. Size frequencies of Yellow Perch in the diet of Double-crested Cormorants breeding on Cat Island, southern Green Bay, WI in 2004 and 2005.

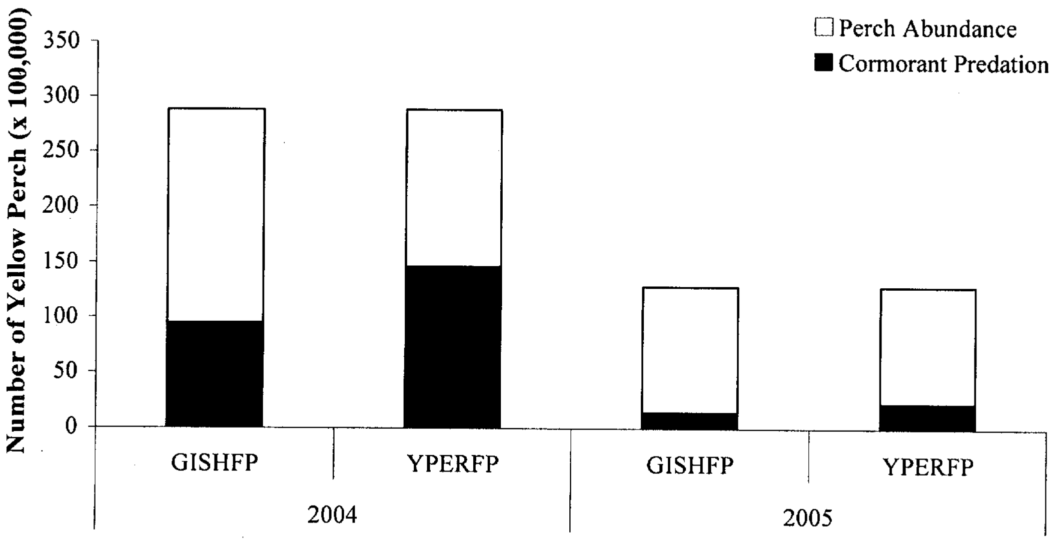

Figure 8. Estimated number of Yellow Perch present in Southern Green Bay, WI in 2004 and 2005 assuming density dependent effects occur prior to the cormorant breeding season and number of Yellow Perch consumed by cormorants estimated by Micro2006b and Endo2006 with Yellow Perch (YPERFP) and Gizzard Shad (GISHFP) input values.

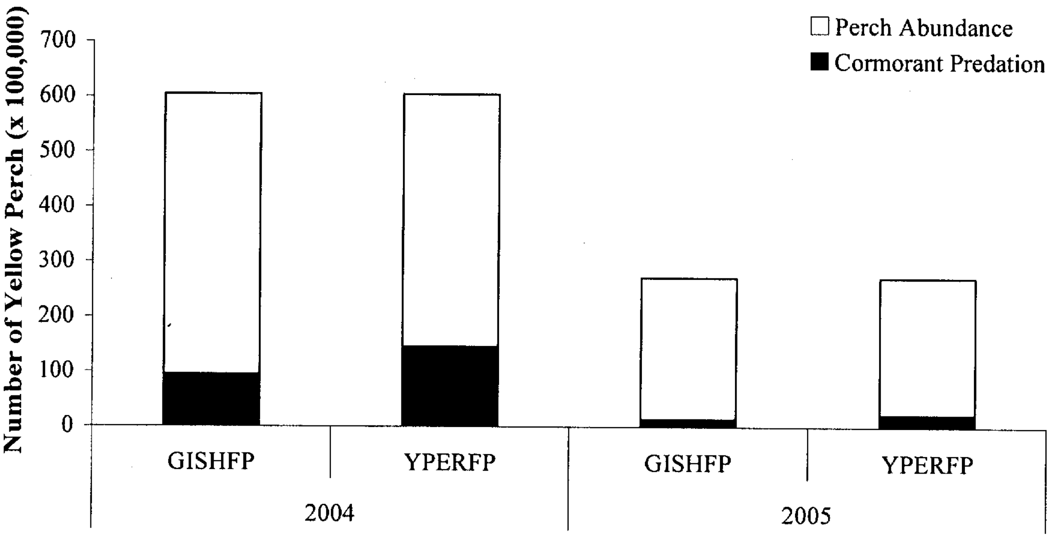

Figure 9. Estimated number of Yellow Perch present in Southern Green Bay, WI in 2004 and 2005 assuming no density dependence and number of Yellow Perch consumed by Cormorants estimated by Micro2006b and Endo2006 with Yellow Perch (YPERFP) and Gizzard Shad (GISHFP) input values.

III. DIFFERENCES IN PREY COMPOSITION OF NESTLING DOUBLE-CRESTED CORMORANT AND AMERICAN WHITE PELICAN REGURGITANT IN SOUTHERN GREEN BAY, WI

ABSTRACT

Regurgitants of nestling Double-crested Cormorants (*Phalacrocorax auritus*) and American White Pelicans (*Pelecanus erythrorhynchos*) were examined with regard to interspecific differences in composition of prey items and exploitation of the Yellow Perch fishery in southern Green Bay Wisconsin. Percent numerical occurrence of select items in cormorant nestling regurgitant was compared to percent occurrence in stomach content analyses of adult to assess the efficacy of regurgitant in evaluating cormorant diet. Cormorants consumed more benthic-dwelling species, such as Round Gobies (*Neogobius melanostomus*) and White Suckers (*Catostomus commersoni*), while pelicans often consumed species that were too large for cormorant consumption, such as Common Carp (*Cyprinus carpio*) and Channel Catfish (*Ictalurus punctatus*). Pelican regurgitant contained primarily young-of –the-year (YOY) Yellow Perch, whereas cormorant regurgitant was composed of multiple year classes, but included no YOY individuals. This is indicative that perch are differentially sensitive to cormorant and pelican predation at different stages in their life cycle. Cormorant regurgitant samples contained a higher proportion of large-bodied fish than stomach contents, and stomach contents contained a higher proportion of soft-bodied and scaleless prey items than regurgitant samples. These findings support that the advanced decomposition of small and soft-bodied prey items in regurgitant may result in a bias in the identification and count of prey species.

INTRODUCTION

North American Double-crested Cormorant (hereafter referred to as cormorant) populations during the first half of the 20th century were characterized by steep population declines attributed to DDT-linked reproductive failure and human persecution (Anderson and Hickey 1975, Postupalsky, 1971, Postupalsky, 1978, Weseloh *et al.* 1995). Reduced persecution and the banning of agricultural pesticides in the early 1970s allowed cormorant populations to rebound and eventually surpass historic population estimates (Weseloh *et al.* 1995). This increase in population was accompanied by concerns that cormorants were depleting stocks of economically-important fish species in their northern breeding colonies (Ludwig *et al.* 1989, Burnett *et al.* 2002, Johnson *et al.* 2002) and southern wintering areas (Glahn and Brugger 1995, Glahn *et al.* 1998, Fenech *et al.* 2004). In 2003, a Public Resource Depredation Order (PRDO) that allowed for the lethal control of cormorant populations considered economically injurious in 24 states was issued (U.S. Fish and Wildlife Service, 2003). Currently, cormorants are subject to active lethal management in Michigan, Minnesota and Mississippi in attempts to alleviate pressure on local fisheries and aquaculture facilities.

Although American White Pelicans (*Pelecanus erythrorhynchos*) hereafter referred to as pelican) often share breeding colonies and foraging habitats with cormorants, the factors that have historically influenced pelican population size and distribution differed from those that effected changes in cormorant numbers. Pelicans exhibited some DDT-linked reproductive impairment, but experienced no associated population declines (Anderson *et al.* 1969, Anderson and Hickey 1975). Pelican populations were primarily impacted by habitat loss resulting from agricultural reclamation of marshes and diversion of water (Thompson

1933, Murphy and Tracy 2005). The response of pelicans to anthropogenic habitat loss was to shift their distributions to the central United States (Liehs and Behle 1964). Migratory patterns and juvenile dispersal of pelicans are highly variable, and estimates of breeding populations across North America are therefore incomplete (Keith 2005). However, general trends in observations of pelican populations indicate that the number of pelicans in North America has increased over the last few decades (Keith 2005, King and Anderson 2005). The migratory route of previously occurring and displaced pelicans breeding in central North America follows Mississippi River drainages (Anderson and Anderson 2005). Increased pelican presence in the southern Mississippi River basin is associated with perceived threats to aquaculture facilities (King and Werner 2001, King 2005).

Cormorants were first recorded nesting on southern Green Bay, Wisconsin in 1973 and thereafter increased 18% per year until 1997, when the population reached an apparent plateau at ~ 2000 breeding pairs (T. Erdman pers. comm.). Pelicans were first reported in 1994, when two nests were recorded. From 1994 to 2002, the local pelican population increased to ~ 200 breeding pairs (T. Erdman pers. comm.). In 2004, the population increased to ~ 500 pairs, an increase presumably linked to abandonment of another Wisconsin breeding site following a flooding event (T. Erdman pers. comm.). The 2005 population was estimated at ~ 600 breeding pairs, indicating that the population displaced in 2004 may have permanently shifted breeding sites. In southern Green Bay, many sport anglers and commercial fishers blame cormorants for declines in local Yellow Perch populations over the last decade. Recent increases in the pelican population have raised similar concerns regarding existing and potential impacts of pelican predation on the perch fishery.

Cormorants are foot-propelled pursuit divers and have been observed diving to 9 m in Green Bay (Custer and Bunck 1992). Pelicans forage exclusively on the water surface in shallow water that is typically 0.3-2.5 m deep (Anderson 1991). Differences in foraging strategies between sympatric cormorant and pelican populations could lead to different food habits. The identification of prey species in regurgitant of nestling cormorants (Craven and Lev 1987, Ludwig *et al.* 1989, Ludwig and Summer 1997-in Diana, Neuman *et al.* 1997, Rudstam *et al.* 2004) and pelicans (Findholt and Anderson 1995*a*, Madden and Restani 2005) has often been used to assess diet. However, if available, stomach content analysis may reduce potential bias in count and identification of prey items (Maruca 1997). The present paper compares regurgitant collected from nestling cormorants and pelicans in southern Green Bay and attempts to identify trends in prey species composition across a temporal scale, placing emphasis on dietary representation of Yellow Perch. Additionally, prey composition of regurgitant from nestling cormorants is compared to composition identified in stomach contents of adult cormorants collected for simultaneous food habits study to assess whether regurgitant samples alone provide valid estimates of diet.

STUDY AREA AND METHODS

Study Area

Sampling was conducted on Cat Island (44°34'N, 88°00 W), a 1-ha breeding colony for cormorants, pelicans, Herring Gulls and Great Egrets located 1 km from the mouth of the Fox River and Lone Tree Island (44°33'N, 87°59 W, Figure 1), a smaller breeding colony for pelicans, Ring-billed Gulls, Great Egrets and Black-crowned Night-herons located directly east of Cat Island across the southern Green Bay shipping channel. Collection of cormorant regurgitant was conducted during June and July from 2000-2005. Pelican regurgitant was collected during June, July, and August from 2001-2005.

Regurgitant Collection

Sampling months encompassed the chick rearing period for each species. From 2000-2003 cormorant regurgitant was collected at irregular intervals during opportunistic colony visits. In 2004 and 2005, in conjunction with a food habits study of adult cormorants, regurgitant was collected on a weekly basis during trips to assess colony reproduction. Nestling cormorants readily regurgitate when approached by humans. Aggregate samples of regurgitant were collected in freezer bags, which were placed in cold storage (-20°C) within 1 hour of collection. From 2001 to 2005 pelican regurgitant was collected according to the same methods described for cormorants during 2000-2003. Nestling pelicans did not regurgitate as readily as cormorants, and often required light handling to induce regurgitation. Consequently, the majority of regurgitant obtained from nestling pelicans was collected during banding operations.

Regurgitant samples were thawed, placed in 70% ethanol, and prey items were separated and identified. Fish were identified to species and measured for wet weight (wwt) and total length (L). If fish were too digested for measurement, they were assigned the mean length of conspecifics in the stomach or for the sample day. Prey items digested to such a degree that they were unrecognizable were excluded from analyses . Allometric equations from Schneider *et al.* (2000) were used to estimate wwt of individuals from L measurements for all prey species except round goby, which was estimated using equations from Phillips *et al.* (2003).

Data Analysis

Differences in consumption of Yellow Perch size classes between cormorants and pelicans were assessed using a two-sample t-test, assuming unequal variances. Within species differences in consumption of perch size classes were compared across years using a one-way analysis of variance. The Bonferroni post-hoc test was used to examine differences between periods, and Levene's test for equality of variances was used to test the assumption of homoscedasticity. Relative importance indices (George and Hadley 1979, Fenech *et al.* 2004) calculated using stomach content data from 2004 and 2005 indicated that Gizzard Shad (*Dorosoma cepedianum*), Round Gobies (*Neogobius melanostomus*), White Suckers (*Catostomus commersoni*) and Yellow Perch were important prey items in cormorant diet (see Chapter 2). To compare regurgitant collection versus stomach content analysis as techniques, percent numerical representation of the four previously mentioned prey species were compared between regurgitant and stomach samples. As most regurgitant samples were collected in June of 2004 and 2005, aggregate prey composition data from regurgitant for June were compared to aggregate data from all June stomach content analyses.

RESULTS

Comparisons of Pelican and Cormorant Regurgigant

Across sample years, 14 species of fish representing 10 families were identified in cormorant regurgitant, and 14 species, representing 9 families were identified in pelican regurgitant (Table 1). Common Carp (*Cyprinus carpio*) and Channel Catfish (*Ictalurus punctatus*) were common in pelican regurgitant, but absent from cormorant samples; Round Gobies and White Suckers occurred more frequently in cormorant diet (Tables 2-5). Yellow Perch were important prey in the diets of both species (Tables 2-5). Across sampled years, perch consumed by cormorants were significantly larger than perch consumed by pelicans ($P < 0.001$, Figure 2). The mean size of Yellow Perch consumed by cormorants differed significantly between sample years. Yellow Perch consumed in 2003 and 2004 were significantly smaller than perch consumed in all other years; perch consumed in 2005 were significantly smaller than those consumed in 2000 and 2001 ($F_{5,483} = 83.89$, $P < 0.001$, Figure 3). While the size of Yellow Perch consumed by pelicans differed between years, there was no evident trend in size classes consumed across years ($F_{4,218} = 16.66$, $P < 0.001$, Figure 4). There were no apparent temporal patterns in pelican diet. Cormorants, by contrast, exhibited an apparent dietary shift from an Alweife-dominated diet in 2000-2001 to a diet where Yellow Perch predominated in 2003-2005 (Figure 5).

Comparisons of Cormorant Regurgitant and Stomach Contents

In 2004, percent numerical occurrences of Yellow Perch in cormorant stomach contents was 25% greater than occurrences in regurgitant samples (Figure 6). Percent occurrence of White Suckers in regurgitant was 87% greater than in stomach contents (Figure 6). In 2005, the percent numerical occurrences of Yellow Perch and White Suckers in regurgitant samples were, respectively, 81% and 80% greater than occurrences stomach contents (Figure 7). Stomach contents contained a percent numerical occurrence of Round Gobies 55% greater than that in regurgitant data (Figure 7).

DISCUSSION

Differences in Cormorant and Pelican Diets

Although there was considerable overlap in prey species presence in cormorant and pelican regurgitant, each species was apparently able to better exploit one or two prey species than the other. Cormorant regurgitant contained much higher numbers of benthic-foraging prey items, such as Round Gobies and White Suckers, that were likely inaccessible to surface foraging pelicans. Alternatively, pelican regurgitant often contained prey such as Common Carp and Channel Catfish that were typically too large for cormorant consumption.

Yellow Perch were common in regurgitant samples of both cormorants and pelicans, though the two species differed in the size classes they most frequently exploited. The Yellow Perch component of pelican regurgitant was composed almost exclusively of young-of-the-year (YOY) Yellow Perch, whereas cormorant regurgitant lacked YOY perch, but age-1 and older individuals. This indicates that perch are differentially vulnerable to cormorant and pelican predation at different stages in the perch life cycle. Pelicans forage cooperatively by collectively herding and concentrating fish in shallow water (Anderson 1991). While cormorants typically forage in large flocks, cooperative behavior is seemingly rare (Glanville 2002). The cooperative concentration of prey coupled with the ability of pelicans to capture large numbers of small prey with a single strike (Anderson 1991) allows them to better exploit YOY year classes than cormorants, which do not typically exhibit cooperative behavior and must frequently pursue individual prey items (Palmer 1962).

Cormorants nesting on Cat Island forage almost entirely in Green Bay (Custer and Bunck 1992). However, pelicans were observed on several occasions arriving and departing the study area by soaring on high thermals. Pelicans often utilize thermals to fly > 100 km to foraging locations (Hall 1925, Johnson and Sloan 1978, Johnsgard 1993, King and Werner 2001), which allows plasticity in resource use (Findholt and Anderson 1995*b*). Therefore, the assumption that the majority of prey items in cormorant regurgitant were removed from Green Bay cannot be applied to prey identified in pelican regurgitant. However, the presence of large numbers of YOY Yellow Perch in pelican regurgitant in 2003 coincided with the production of the largest Yellow Perch year class in 25 years in southern Green Bay, indicating perch consumed during this period originated from Green Bay.

Stomach Contents versus Collected Birds

Comparisons between regurgitant samples and stomach contents of cormorants did not yield similar estimates of prey species composition. Soft-bodied scaleless species decompose more quickly than fishes with rough scales (Brugger 1992). Thus, the smaller, soft-bodied species may not be adequately identified in advanced states of digestion that often characterize regurgitant samples. Stomach content data collected from cormorants indicated that Gizzard Shad were the single most important prey species in late summer/early fall (see Chapter 2), after chicks had fledged and regurgitant was no longer available for collection. In the absence of stomach content data, analysis of regurgitant samples would not have regarded shad as an important component of cormorant diet in 2004 and 2005. Gizzard Shad degrade rapidly when ingested and cormorants fed a Gizzard Shad diet do not eject bony pellets (Brugger 1993), suggesting that if cormorants begin consuming Gizzard Shad earlier in the breeding season, Gizzard Shad still might go undetected in regurgitant samples. White Suckers, which constituted the majority of large-bodied prey items across sampling methods, had a greater proportional representation in regurgitant samples than stomach contents in both years. This difference may be indicative of sampling bias in the collection of regurgitant samples. The large size of White Suckers makes them more visible to individuals collecting regurgitant, potentially resulting in a disproportionately high estimate of White Sucker presence in cormorant diet. Derby and Lovvorn (1997) suggested that calculation of prey composition of cormorant pellets and stomachs of collected birds could lead to different inferences regarding diet composition, and suggested that pellet-based estimates of diet required consistent and meticulous sampling of colonies. While no pellets were collected during the present study, the disparity in percent composition of important prey items clearly leads to different inferences of diet composition. Future studies utilizing regurgitant-based methods for examining food habits of both cormorants and pelicans in southern Green Bay and elsewhere should include more consistent visits to breeding colonies and a more specific methodology for collecting regurgitant samples.

Management Implications

While concerns have been expressed regarding pelican predation of sport and commercial fish resources (King and Werner 2001), the conservation and protection of pelican populations in North America remains a priority (Stapp and Hayward 2002, Anderson and King 2005). In the southeastern United States, pelicans are not considered a sufficient threat to fisheries and aquaculture operations to warrant wide-spread lethal control (King 2005). However, recent research suggests the implementation of abatement techniques in the southeastern United States is warranted (King 2005). Consumption of different Yellow Perch size classes by cormorants and pelicans suggests that these species would require independent management strategies with regard to the Yellow Perch fishery. In an attempt to reduce predation on the Yellow Perch population, the oiling of cormorant eggs and culling of cormorants at two Green Bay colonies, including Cat Island is scheduled for the 2006 breeding season. The use of pyrotechnics and harassment have effectively reduced losses to aquaculture facilities in Louisiana (King 2005). Pelican-linked losses to the Yellow Perch fishery in southern Green Bay may be reduced by employing similar abatement techniques during perch spawning.

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Table 1. Prey species identified in regurgitant of nestling Double-crested Cormorants on Cat Island from 2000-2005 and from nestling American White Pelicans on Cat Island and Lone Tree Island from 2001-2005 in southern Green Bay, WI.

Family	Common Name	Scientific Name	Species Presence Cormorant Regurgitant	Species Presence Pelican Regurgitant
Catostomidae				
	Northern Hog Sucker	*Hypentelium nigricans*		*X*
	Quillback	*Caproides cyprinus*	X	
	White Sucker	*Catostomus commersoni*	*X*	*X*
Centrarchidae				
	Bluegill	*Lepomis machrochirus*	*X*	
Clupeidae				
	Alewife	*Alosa pseudoharengus*	*X*	*X*
	Gizzard Shad	*Dorosoma cepedianum*	*X*	*X*
Cyprinidae				
	Common Carp	*Cyprinus carpio*		*X*
	Spottail Shiner	*Notropis hudsonius*	*X*	*X*
Cyprinodontidae				
	Banded Killifish	*Fundulus diaphanus*		*X*
Gobiidae				
	Round Goby	*Neogobius melanostomus*	*X*	*X*
Ictaluridae				
	Channel Catfish	*Ictalurus punctatus*		*X*
Osmeridae				
	Rainbow Smelt	*Osmerus mordax*	*X*	
Percicthyidae				
	White Bass	*Morone chrysops*	*X*	*X*
	White Perch	*Morane americana*	*X*	*X*
Percidae				
	Walleye	*Stizostedion vitreum*	*X*	*X*
	Yellow Perch	*Perca flavescens*	X	X
Percopsidae				
	Trout Perch	*Percopsis omiscomaycus*	X	
Sciaenidae				
	Freshwater Drum	*Aplodinotus grunniens*	X	X

0.46 0.46 0.5

Table 2. Number of prey items identified in regurgitant of nestling Double-crested Cormorants on Cat Island, southern Green Bay, Wisconsin, 2000-2005

	2000		2001		2002		2003		2004		2005	
Species	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Alewife	71	78.89	222	89.88	3	0.81	115	14.15	4	0.62	15	1.55
Bluegill	1	1.11	0	0.00	0	0.00	4	0.49	1	0.16	0	0.00
Channel Catfish	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Freshwater Drum	0	0.00	0	0.00	15	4.03	0	0.00	1	0.16	14	1.45
Gizzard Shad	0	0.00	0	0.00	173	46.51	2	0.25	2	0.31	0	0.00
Quillback	0	0.00	0	0.00	2	0.54	0	0.00	0	0.00	3	0.31
Round Goby	0	0.00	0	0.00	0	0.00	6	0.74	130	20.28	237	24.51
Smelt	0	0.00	0	0.00	1	0.27	0	0.00	0	0.00	4	0.41
Spottail Shiner	4	4.44	0	0.00	2	0.54	0	0.00	66	10.30	39	4.03
Trout Perch	0	0.00	0	0.00	0	0.00	0	0.00	9	1.40	72	7.45
Walleye	0	0.00	0	0.00	24	6.45	2	0.25	25	3.90	25	2.59
White Bass	0	0.00	0	0.00	3	0.81	0	0.00	4	0.62	0	0.00
White Perch	9	10.00	13	5.26	66	17.74	0	0.00	5	0.78	52	5.38
White Sucker	0	0.00	4	1.62	22	5.91	10	1.23	16	2.50	94	9.72
Yellow Perch	5	5.56	8	3.24	61	16.40	674	82.90	378	58.97	412	42.61
Total	90	100	247	100	372	100	813	100	641	100	967	100

Table 3. Number of prey items identified in regurgitant of nestling American White Pelicans on Cat Island and Lone Tree Island, southern Green Bay, Wisconsin, 2001-2005

	2001		2002		2003		2004		2005	
Species	No.	%	No.	%	No.	%	No.	%	No.	%
Alewife	21	2.71	2	0.42	114	2.68	28	0.40	0	0.00
Carp	5	0.65	0	0.00	5	0.12	10	0.14	0	0.00
Channel Catfish	5	0.65	0	0.00	1	0.02	5	0.07	3	0.08
Freshwater Drum	7	0.90	0	0.00	1	0.02	1	0.01	1	0.03
Gizzard Shad	7	0.90	0	0.00	0	0.00	0	0.00	0	0.00
Hognose Sucker	1	0.13	0	0.00	0	0.00	0	0.00	0	0.00
Killfish	0	0.00	1	0.21	0	0.00	0	0.00	0	0.00
Round Goby	0	0.00	0	0.00	0	0.00	20	0.29	1	0.03
Spottail Shiner	0	0.00	0	0.00	2	0.05	27	0.39	0	0.00
Shiner sp.	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00
Walleye	1	0.13	0	0.00	0	0.00	4	0.06	0	0.00
White Bass	0	0.00	0	0.00	0	0.00	2	0.03	0	0.00
White Perch	7	0.90	2	0.42	0	0.00	2	0.03	0	0.00
White Sucker	2	0.26	0	0.00	0	0.00	7	0.10	0	0.00
Yellow Perch	719	92.77	468	98.94	4094	96.10	6855	98.43	3812	99.87
Unidentifiable	0	0.00	0	0.00	43	1.01	2	0.03	0	0.00
Total	775	100	473	100	4260	100	6964	100	3817	100

Table 4. Total biomass (g) of prey items identified in regurgitant of nestling Double-crested Cormorants on Cat Island, southern Green Bay, Wisconsin, 2000-2005

	2000		2001		2002		2003		2004		2005	
Species	Wt.	%	Wt.	%	Wt.	%	Wt.	%	Wt.	%	Wt.	%
Alewife	418.92	62.00	672.47	78.46	24.36	0.24	653.86	22.85	0.00	0.00	57.30	1.26
Bluegill	0.00	0.00	0.00	0.00	0.00	0.00	92.45	3.23	63.19	2.17	0.00	0.00
Channel Catfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Freshwater Drum	0.00	0.00	0.00	0.00	457.62	4.58	0.00	0.00	7.99	0.27	108.30	2.38
Gizzard Shad	0.00	0.00	0.00	0.00	719.45	7.20	3.41	0.12	0.00	0.00	0.00	0.00
Quillback	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Round Goby	0.00	0.00	0.00	0.00	0.00	0.00	67.04	2.34	451.92	15.50	470.90	10.35
Smelt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spottail Shiner	0.00	0.00	0.00	0.00	8.27	0.08	0.00	0.00	160.81	5.52	94.50	2.08
Trout Perch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	29.27	1.00	82.10	1.80
Walleye	0.00	0.00	0.00	0.00	1735.09	17.36	0.00	0.00	526.00	18.04	862.65	18.95
White Bass	0.00	0.00	0.00	0.00	251.93	2.52	0.00	0.00	29.94	1.03	0.00	0.00
White Perch	110.45	16.35	55.73	6.50	4027.67	40.30	0.00	0.00	38.02	1.30	390.70	8.58
White Sucker	0.00	0.00	0.00	0.00	694.67	6.95	627.87	21.94	188.10	6.45	719.70	15.81
Yellow Perch	146.35	21.66	128.90	15.04	2074.82	20.76	1417.15	49.52	1420.33	48.72	1765.60	38.79
Total	675.72	100	857.10	100	9993.88	100	2861.79	100	2915.58	100	4551.75	100

Table 5. Total biomass (g) of prey items identified in regurgitant of nestling American White Pelicans on Cat Island and Lone Tree Island, southern Green Bay, Wisconsin, 2001-2005

	2001		2002		2003		2004		2005	
Species	Wt.	%	Wt.	%	Wt.	%	Wt.	%	Wt.	%
Alewife	0.00	0.00	0.00	0.00	2020.53	36.21	0.00	0.00	0.00	0.00
Carp	702.70	11.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Channel Catfish	1181.10	18.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Freshwater Drum	1409.70	22.60	0.00	0.00	318.56	5.71	0.00	0.00	0.00	0.00
Gizzard Shad	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hognose Sucker	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Killfish	0.00	0.00	3.15	0.29	0.00	0.00	0.00	0.00	0.00	0.00
Round Goby	0.00	0.00	0.00	0.00	0.00	0.00	138.25	8.50	0.00	0.00
Spottail Shiner	0.00	0.00	0.00	0.00	17.61	0.32	146.22	8.99	0.00	0.00
Shiner sp.	0.00	0.00	0.00	0.00	0.00	0.00	24.07	1.48	0.00	0.00
Walleye	319.59	5.12	0.00	0.00	0.00	0.00	177.10	10.89	0.00	0.00
White Bass	0.00	0.00	0.00	0.00	0.00	0.00	7.79	0.48	0.00	0.00
White Perch	848.11	13.59	267.85	24.78	0.00	0.00	6.73	0.41	0.00	0.00
White Sucker	591.22	9.48	0.00	0.00	0.00	0.00	853.43	52.48	0.00	0.00
Yellow Perch	1186.39	19.02	809.86	74.93	3224.06	57.77	272.54	16.76	4764.45	100.00
Unidentifiable	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	6238.81	100	1080.85	100	5580.76	100	1626.13	100	4764.45	100

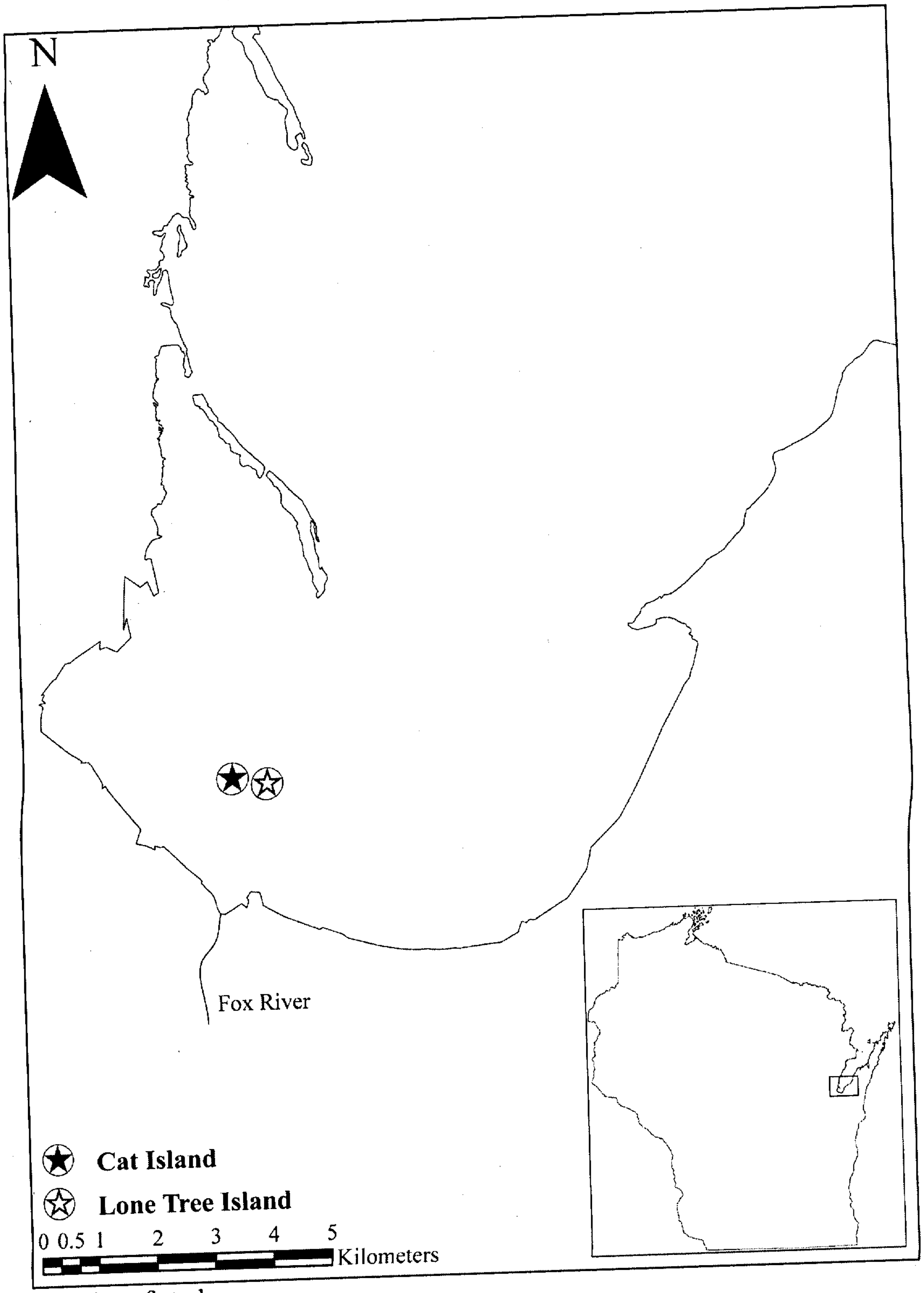

Figure 1. Map of study area.

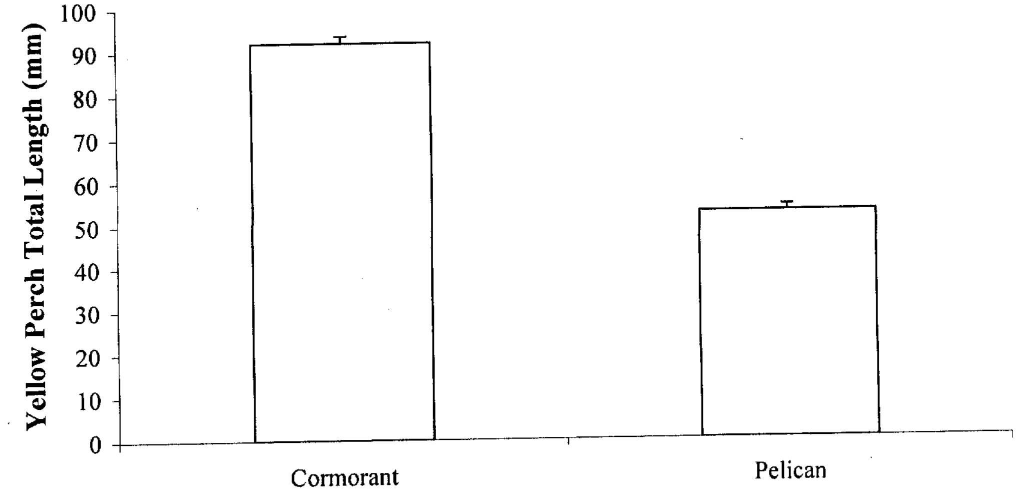

Figure 2. Differences in size classes of Yellow Perch identified in regurgitant of nestling Double-crested Cormorants on Cat Island, southern Green Bay, WI from 2000-2005 and nestling American White Pelicans on Cat Island and Lone Tree Island from 2001 2005. Values are means with standard error bars.

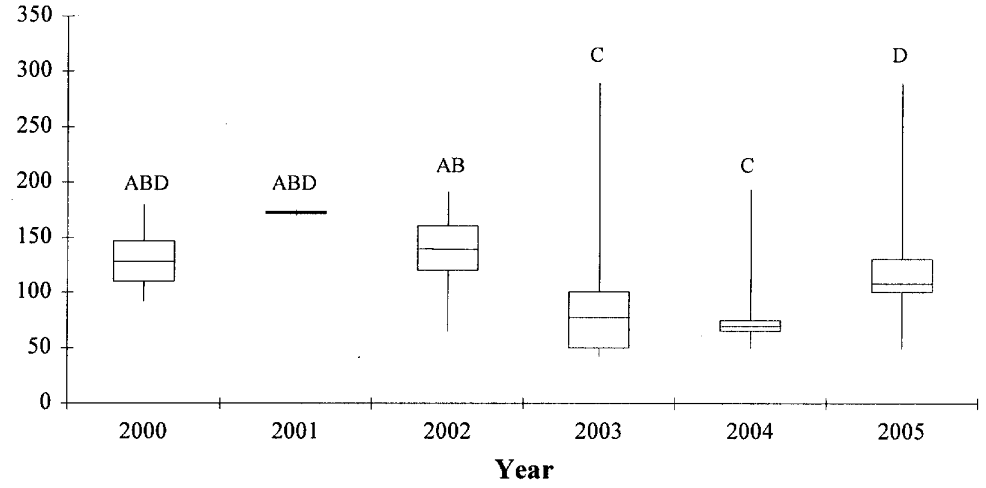

Figure 3. Total lengths of Yellow Perch identified in regurgitant of nestling Double-crested Cormorants on Cat Island, southern Green Bay, WI from 2000-2005. Boxes represent the first and third quartiles and are bisected by the median. Lines perpendicular to boxes represent minimum and maximum measured values.

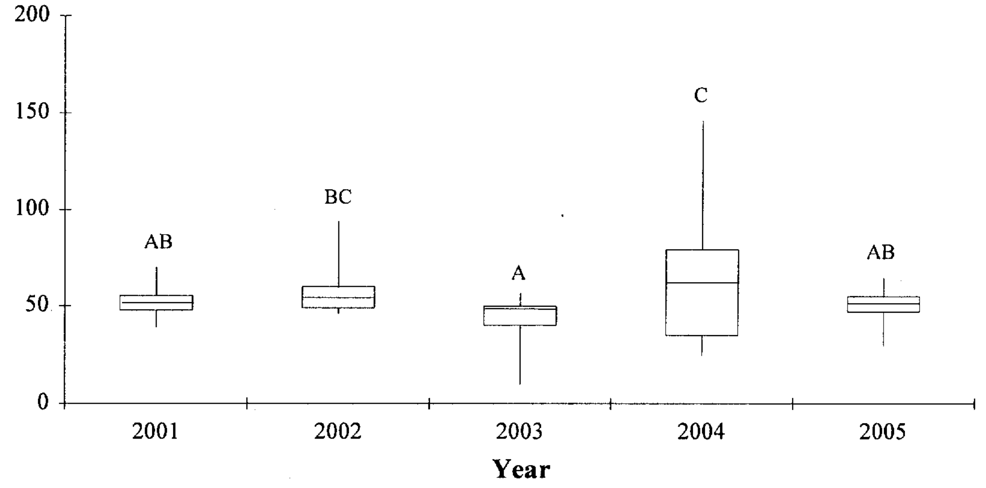

Figure 4. Total lengths of Yellow Perch identified in regurgitant of nestling American White Pelicans on Cat Island and Lone Tree Island, southern Green Bay, WI from 2001 2005. Boxes represent the first and third quartiles and are bisected by the median. Lines perpendicular to boxes represent minimum and maximum measured values.

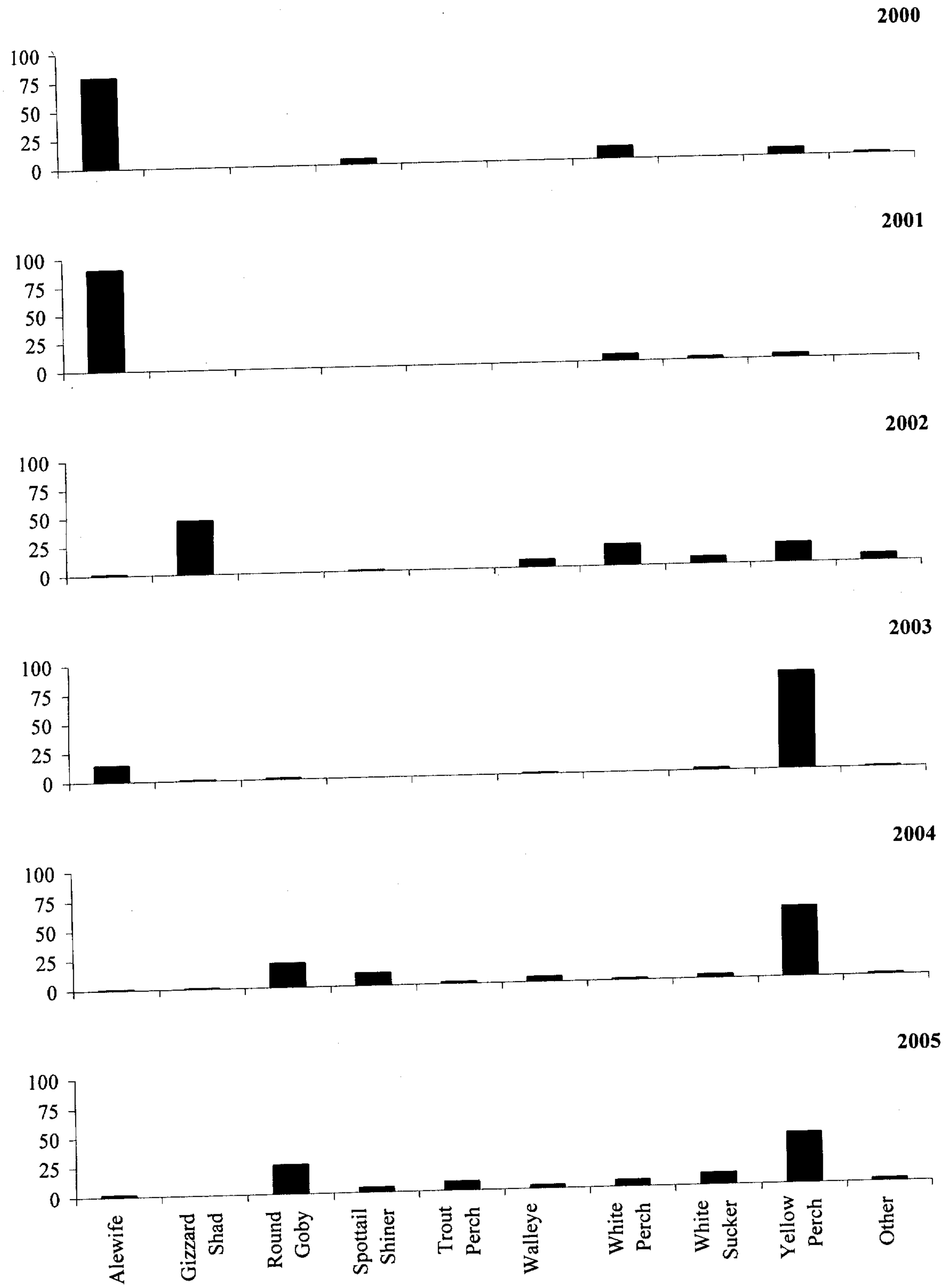

Figure 5. Percent composition of predominant prey species in regurgitant from nestling Double-crested cormorants on Cat Island, southern Green Bay, WI, from 2000-2005

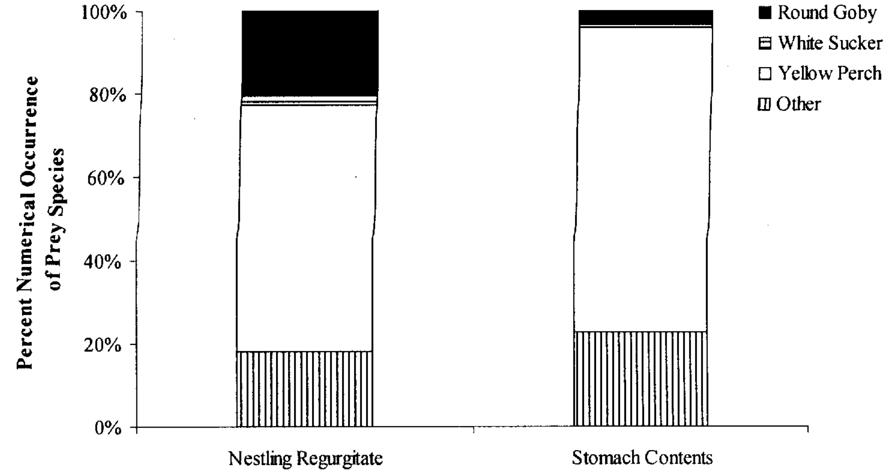

Figure 6. Differences in percent numerical occurrence of prey species of high relative importance identified in nestling regurgitant and adult stomach contents of Double crested Cormorants on Cat Island, southern Green Bay, WI, in 2004.

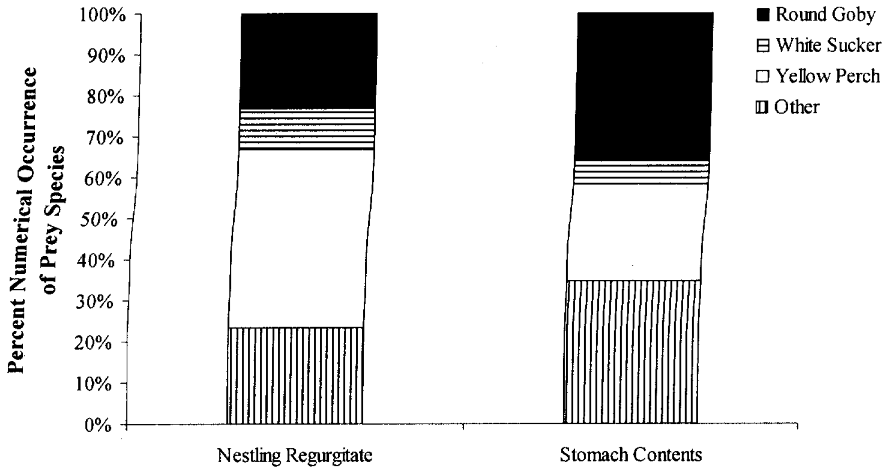

Figure 7. Differences in percent numerical occurrence of prey species of high relative importance identified in nestling regurgitant and adult stomach contents of Double crested Cormorants on Cat Island, southern Green Bay, WI, in 2005.